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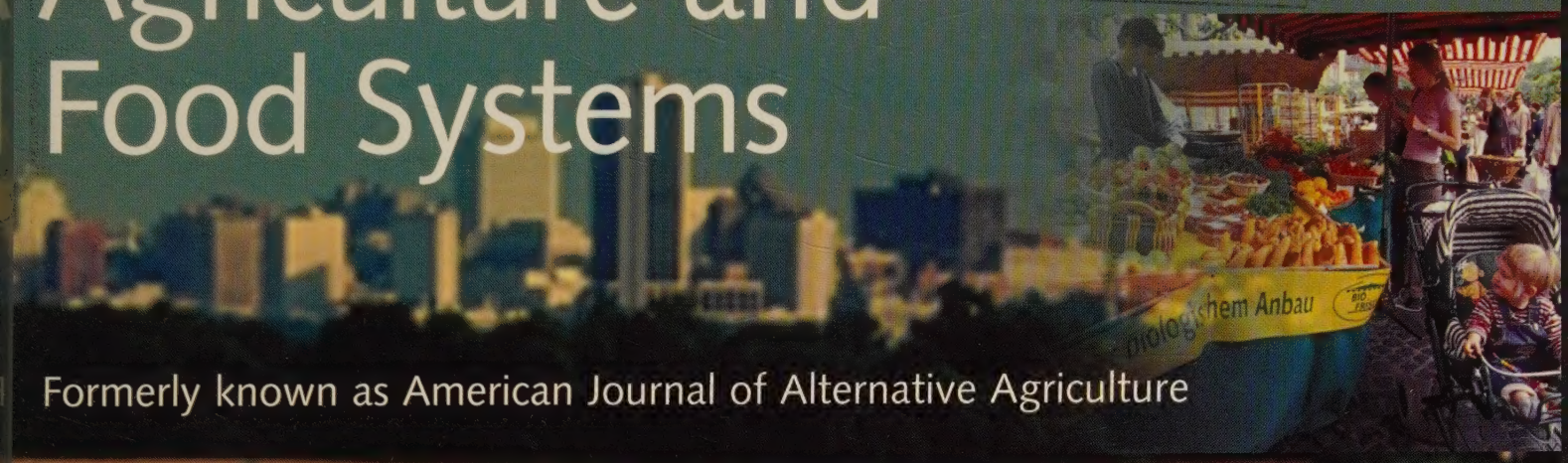

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Renewable Agriculture and Food Systems provides an international forum for original research and review articles on the biological, physical, social science, and policy aspects of alternative agriculture and food systems, focusing on the effective use of renewable resources and biodiversity in agro-ecosystems. The journal particularly welcomes multidisciplinary, holistic, systems research that addresses the multiple challenge of economically meeting basic human needs for food, fiber, and energy while maintaining essential natural and environmental resources.

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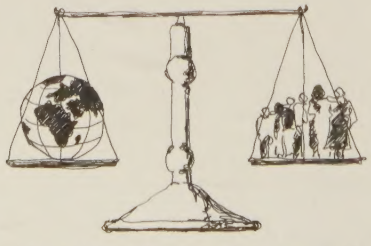

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Volume 20 Number 4 December 2005

Review Article

Comparison of consumer perceptions and preference toward organic versus conventionally produced foods: A review and update of the literature
Emmanuel K. Yiridoe, Samuel Bonti-Ankomah and Ralph C. Martin 193

Research Papers

Organic cucumber production in the greenhouse: A case study from Turkey
Y. Tuzel, A. Gul, O. Tuncay, D. Anac, N. Madanlar, Z. Yoldas, M. Gumus, I.H. Tuzel and S. Engindeniz 206

Substrates and fertilization for the rustic cultivation of *in vitro* propagated native orchids in Soconusco, Chiapas
Anne Damon, Marco Pérez Soriano and Maria del Lourdes Rivera 214

An integrated approach to crop/livestock systems: Forage and grain production for swath grazing
D.L. Tanaka, J.F. Karn, M.A. Liebig, S.L. Kronberg and J.D. Hanson 223

An integrated approach to crop/livestock systems: Wintering beef cows on swathed crops
J.F. Karn, D.L. Tanaka, M.A. Liebig, R.E. Ries, S.L. Kronberg and J.D. Hanson 232

Farmer research: Conventional experiences and guidelines for alternative agriculture and multi-functional agro-ecosystems
C.S. Wortmann, A.P. Christiansen, K.L. Glewen, T.A. Hejny, J. Mulliken, J.M. Peterson, D.L. Varner, S. Wortmann and G.L. Zoubek 243

Marketing locally produced foods: Consumer and farmer opinions in Washington County, Nebraska
Mindi L. Schneider and Charles A. Francis 252

The adoption and impact of management intensive rotational grazing (MIRG) on Connecticut dairy farms
Jeremy Foltz and Gillis Lang 261

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Comparison of consumer perceptions and preference toward organic versus conventionally produced foods: A review and update of the literature

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Abstract

Growing interest in organic agriculture has prompted numerous studies that compare various aspects of organic and conventionally produced foods. This paper provides a comprehensive evaluation of empirical studies comparing organic products and conventionally grown alternatives. The emphasis is on key organic consumer demand and marketing issues, including: (1) the implications of an economic definition of organically grown food for consumer demand; (2) attributes that shoppers consider most when comparing organic with conventionally grown products; (3) level and characteristics of consumer knowledge and awareness about organic food; (4) assessment methods and characteristics of organic consumer attitudes and preferences; (5) size of price premium and characteristics of consumers' willingness-to-pay for organic products; and (6) profile of organic consumers. Overall, although there is some knowledge and awareness about organic products, consumers are not consistent in their interpretation of what is organic. Secondly, while consumers typically understand the broad issues about organic foods, many tend not to understand the complexities and niceties of organic farming practices and organic food quality attributes. Uncertainty regarding the true attributes of organic, and skepticism about organic labels, part of which stems from reported cases of (inadvertent) mislabeling, and product misrepresentation, and partly because of nonuniform organic standards and certification procedures, may hold some consumers back from purchasing organic. Thirdly, concern for human health and safety, which is a key factor that influences consumer preference for organic food, is consistent with observed deterioration in human health over time and, therefore, motivates consumers to buy organic food as insurance and/or investment in health. Fourthly, the proportion of consumers who are willing to pay a price premium for organic food decreases with premium level. On the other hand, premiums tend to increase with (combinations of) preferred attributes. In addition, demand tends to depend more on the price differential with respect to conventionally grown products, than on actual price. In contrast to sensitivity of demand to changes in price, income elasticity of demand for organic foods is generally small. Finally, it is important for policy analysts and researchers to note that organic fresh fruits and vegetables currently dominate the organic consumer's food basket. Furthermore, it is not clear whether frequent buyers consider particular organic products (e.g., organic meat) as normal goods, or if consumers consider such products as luxury goods.

Key words: consumer attitudes and preferences, credence good, organic food attributes, price premium, willingness-to-pay

Introduction

Interest in organically produced food is increasing throughout the world in response to concerns about conventional agricultural practices, food safety and human health concerns[1–3], animal welfare considerations[4,5] and concern about the environment[6,7]. These concerns, along with observed organic consumer behavior, led Davies et al.[8]

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to identify several categories of organic consumers, namely environmentalists, food phobics, healthy eaters, humanists and welfare enthusiasts, and hedonists. The interest in organic agriculture has prompted numerous studies comparing aspects of organic and conventionally produced foods. Growing interest among stakeholders (such as policy analysts, consumers, etc.) has also prompted a need to not only determine the extent to which there is a scientific basis for claims in support of organic products, but also to consolidate and evaluate the numerous empirical studies and findings. Bourn and Prescott[9], for example, provided an excellent review of several studies comparing selected biophysical and related quality attributes of organic and conventionally produced foods. In an earlier study, Woese and others[10] assessed selected studies using physico-chemical quality attributes for various food groups, including cereals and cereal products, potatoes, vegetables and vegetable products, wines, beers, bread, dairy products, meat and eggs, fruits, and nuts and oil seeds.

The future of organic agriculture will depend, to a large extent, on consumer demand. Thus, a consumer-oriented approach to understanding organic agriculture is important not only in its own right, but also in terms of shifting market dynamics. This could also vary depending on the region of the world. Thus, a clear understanding of consumer attitudes, and the motivations underlying actions in responding to organically grown products is important.

This review complements and extends the work of Bourn and Prescott[9] and Woese and others[10]. We have consolidated and compared numerous empirical studies on consumer preferences for, and attitude towards, organic food, relative to conventionally grown products. The literature review emphasizes important organic consumer demand and marketing issues, including: (1) the implications of an economic definition of organically grown food for consumer demand; (2) attributes that shoppers consider most when comparing organic with conventionally grown products; (3) level and characteristics of consumer knowledge and awareness about organic food; (4) assessment methods and characteristics of organic consumer attitudes and preferences; (5) size of organic price premium and characteristics of consumers' willingness-to-pay for organic products; and (6) profile of organic consumers. Such a comparison across studies, and for various countries, is not only important in its own right, but also provides a better understanding of the economic and noneconomic variables to include in organic consumer demand modeling and estimation. In the following, an economic perspective of organic products as economic goods precedes a comparison of selected consumer decision-making dimensions of organic products.

What is Organic? The Role of Economics

The most common definitions of an organically produced food emphasize the technology or production practices and principles used, and/or the 'organic philosophy'[11–14]. Thus, while some definitions highlight dimensions such as 'biological' or 'natural' production systems[12] and 'green' or 'environmental friendliness'[13], others emphasize the limited use of artificial chemicals in organic production[11], or its general philosophy[14].

Organic food consumers tend to perceive such products as having particular intrinsic (quality and safety) characteristics[15]. In practice, a consumer's decision choice in favor of organic is made by comparing a bundle of (observable and unobservable) characteristics of the good. This notion of a good leads logically to a perspective by economists —first developed by Nelson[16] and Darby and Karni[17]— namely, credence characteristics. As a credence good, information about an organic product is asymmetric[18,19]. That is, consumers may not detect the presence or absence of organic characteristics even after purchase and use. Consumers may only know that the product is organic when they are informed[18].

According to Hansen[19], the characteristics of organic foods that are important to consumers can be grouped into general and commodity-specific attributes. General attributes relate to food safety and human health, environmental effects and farm animal welfare aspects, while commodity-specific attributes include variables such as visual appeal, nutritional value, taste, freshness, etc. In contrast, Caswell[20] identified five broad groups of food quality attributes, namely safety, nutrition, value, package and production process (Table 1). Although consumers may not adequately differentiate between organic and conventional products with respect to their general attributes, they may recognize the unique taste, visual appeal or freshness of particular products. However, sensory characteristics (i.e., product taste, visual appeal and freshness), alone, may not be sufficient in determining whether a product is organic or not. Consequently, quality signals, such as product labels, help transform credence characteristics into search attributes, thereby enabling buyers to more clearly assess product quality.

A key benefit of the quality attributes of food products (see Table 1), is in terms of human health[20]. In connection with this, Grossman[2] applied Lancaster's[21] theory of consumer demand to develop a model of consumer demand for 'good health'. Grossman[2] viewed human health as a commodity (i.e., durable capital stock) that produces an output of healthy time, and which depreciates with age. Thus, one determines one's optimal stock of health capital at any age by comparing the marginal efficiency of such capital with its user cost (in terms of the price of gross investment on improved health). Observed deterioration in human health over time therefore motivates an individual to protect against such depreciation losses by purchasing various types of 'insurance' and/or holding an excess stock of health. An example of such 'insurance' that a consumer may consider purchasing is healthy food. The characteristics of organic food may therefore be an input into the consumer's demand function for 'good health', while the price of organic food becomes the cost of the investment in

Table 1. Some quality attributes of (organic and conventionally produced) food products (source: Caswell[20]).

Quality attribute	Examples
Food safety attributes	Food-borne pathogens Heavy metals Pesticide residues Food additives Naturally occurring toxins Veterinary residues
Nutrition attributes	Fat Calories Fiber Sodium Vitamins Minerals
Value attributes	Purity Compositional integrity Size Appearance Taste Convenience of preparation
Package attributes	Package materials Labeling Other information provided
Production process attributes	Animal welfare Genetic modification Environmental impact Pesticide use Worker safety

'good health'. The above discussion links food-quality attributes with consumer demand for organic food. This raises questions regarding how organic products compare with conventionally grown alternatives.

Comparison of Organic and Conventionally Grown Produce

Although the attributes associated with organic foods may be difficult to identify by visual inspection alone, most consumers purchase organic products because of a perception that these products have unique (and in some cases superior) attributes compared to conventionally grown alternatives[15]. On the other hand, a major reason why some consumers do not purchase organic food is linked to a perception that such foods are not better than their conventionally grown alternatives[22]. There is therefore continuing interest and debate about whether organically grown products are superior to and/or different from conventionally produced alternatives and, if so, in terms of what characteristics.

Several studies have assessed whether there are differences between organic and conventional foods from the perspective of both the producer (or supply side) and the consumer (or demand side). Supply-side investigations typically focus on yield, producer price and profitability comparisons. In contrast, demand-side studies have investigated the differences in terms of biophysical and chemical characteristics, as well as consumer preferences and (retail) prices. Given that the emphasis of this study is on consumer perceptions and demand, the rest of this section focuses on comparison of demand-side characteristics.

What noneconomic attributes are important to organic shoppers?

What are the key noneconomic attributes that shoppers consider when comparing organic produce with conventionally grown alternatives? Nutritive, sensory and food-safety attributes influence consumer choice between organic and conventionally produced foods[9]. Several studies have therefore compared organic and conventionally produced foods using such attributes. Although shoppers generally link produce quality with its appearance[23], Goldman and Clancy[24] reported a relationship between consumer willingness to accept blemishes and organic produce purchase behavior. In general, appearance tends to be less important among consumers with a high preference for organic and pesticide-free products[25].

Product taste (i.e., flavor), freshness and shelf life are other characteristics that shoppers consider in their purchase decisions. There is contrasting empirical evidence on the role that taste, freshness and storage life play in consumer decisions. For example, some studies reported that consumers perceive no difference in the taste of organic food versus conventionally grown alternatives[26,27], while other studies report a better taste for organic produce[28,29]. The differences and conclusions on taste, freshness and shelf life, where they exist, appear to be linked to the existing (organic versus nonorganic) food-buying habits of the survey respondent[27].

Overall, a review of various comparative studies indicates contrasting conclusions regarding the nutritive value of organic products (see also Bourn and Prescott[9] and Woese and others[10]). For example, several of the studies reported that organic products have lower nitrate content, and higher dry matter and mineral content, compared to conventionally grown alternatives[30–35]. Furthermore, while some studies reported higher vitamin C content in organically grown foods[35,36], others found higher vitamin C levels in conventionally grown produce[31,37], with the contrasting findings attributed in part to factors such as maturity at harvest and storage conditions[9].

Some of the contrasting findings from the various comparative studies have also been attributed to differences in research methods and experimental conditions[9,10]. For example, some studies report that crop variety, soil type, climate, duration of experiment, post-harvest practices and statistical design can all influence the nutritive and sensory characteristics of a product[9,10,32,38]. Thus, it is important for future efforts at comparing organic and conventional production processes and products to control for, or address,

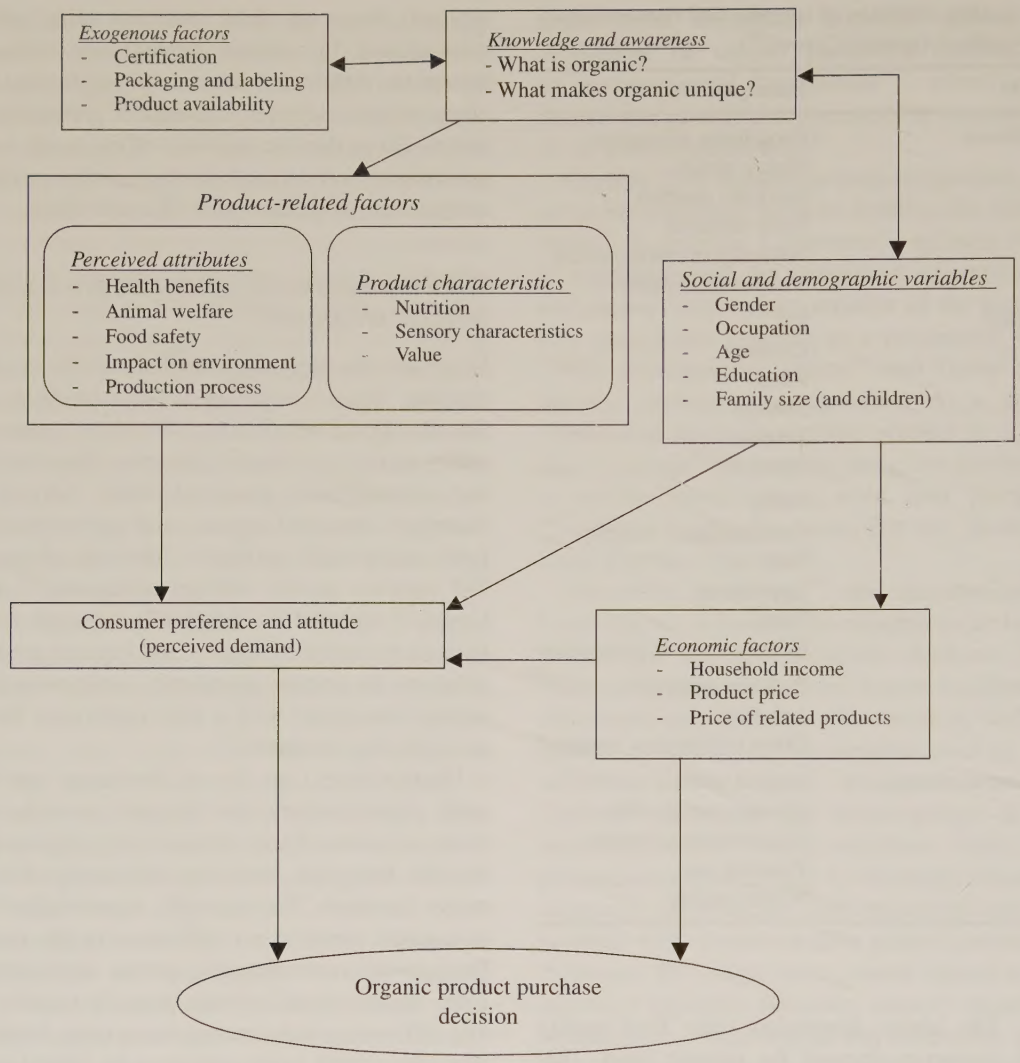

Figure 1. Conceptual framework of factors that affect organic consumer attitudes and purchase decisions.

such methodological and research design issues. There is also no consistent or clear relationship between the various findings and location of the study. Thus, although some researchers suggest that soil type and climate affect nutritive and sensory characteristics of foods, an examination of particular crops within similar regions and/or conditions indicate contrasts in some of the findings[32–34,39].

Furthermore, other studies that investigated a perception that organically grown foods have less chemical and microbial contamination than conventionally produced foods[40–42] also report contrasting conclusions. Thus, it is not clear that, overall, organic foods are safer than conventionally grown foods. Perceptions that organic is associated with less or no chemical residues is also sometimes questioned because of the potential for contamination during processing, and the possibility of mixing organic and conventional products in the food distribution chain. There is also a possibility of organic produce carrying a higher risk of microbial contamination than conventional foods because the increased use of manure (as opposed to chemical fertilizer) in organic agriculture can increase the incidence of contamination from pathogens such as *Salmonella* species and *Escherichia coli*[40]. However, such risks can be reduced with proper management practices[9,43].

Consumer Awareness and Knowledge about Organic Food

The environmental ethic that gained worldwide prominence with Earth Day 1990 placed emphasis on individual responsibility (for personal health) and social action (on environmental quality and animal welfare)[44,45]. Personal responsibilities include making informed consumer choices. This, in turn, requires consumer knowledge and awareness about competing products. Knowledge and awareness have other direct and indirect effects on attitudes toward consumer products, and willingness to pay a price premium (Fig. 1). Because organic products are credence goods, consumers (unlike producers who are aware that their products are organic) may not know whether a product is produced using organic or conventional methods, not even after

repeated purchase and consumption, unless they are told so[18]. Thus, awareness and knowledge about organic products are critical in the consumer purchase decision. If an individual cannot clearly differentiate between two alternative products, a price premium on the organic product can confuse and/or affect the individual's purchasing decision in favor of the cheaper product.

A review of selected studies on consumer awareness and knowledge about organic foods suggests that while there is a general consumer awareness around the world, consumers (sometimes within the same country) have inconsistent interpretations about what is 'organic'. For example, in a survey of consumers in three California counties, Jolly and co-authors[22] found that respondents associated organic produce with no pesticides, no artificial fertilizer, no growth regulators and residue-free products. Similarly, survey respondents in the UK perceived 'organic farming' to imply absence of chemicals, 'absence of growth hormones' and 'not intensively grown' or 'products grown naturally'[42]. In a more recent study for the UK, respondents described organically produced food as food that is more natural and healthy, compared to conventionally produced food[46]. Furthermore, in the UK study, there was no difference in consumers' understanding of 'organic' among organic and nonorganic food buyers. In other words, both buyers of organic and nonorganic products felt that organic alternatives have no pesticides and/or use no chemical fertilizers, and are natural and healthy. In contrast, Jolly[45] reported a substantial difference in how US buyers and nonbuyers rated organic product quality, compared to conventionally grown products.

Although consumers typically understand the general issues associated with organic farming, many tend not to understand the complexities and niceties of organic farming practices, and the associated quality attributes outlined in Table 1[46]. This hypothesis by Hill and Lynchehaun[46] helps to explain why some studies[47,48] reported confusion and/or inconsistencies with consumers' understanding of the organic concept. Wolf[48], for example, found that US consumers rated the attributes associated with organic lettuce (such as environmental friendliness) as 'somewhat desirable' or 'very desirable', while the 'certified' organic label was rated as only 'slightly desirable' or 'somewhat desirable'.

Hutchins and Greenhalgh[47] also noted some inconsistencies among consumers in the UK, where one-third of respondents reported that they were aware of existing organic labels, yet some of such respondents did not recognize the symbol or logo of the organic food standards regulatory body in the country. Similar observations were reported for consumers in Greece[49]. These observations have led some analysts to assert that, with the emergence of other types of labels in the market (such as 'vegetarian' or 'healthy' alternatives), the confusion will likely intensify[47].

Many organic consumers identify organic products based on the organic labels and/or organic logos attached. Indeed, several studies have found a positive relationship between consumer purchase decisions and organic product labeling[50–53]. Consumers generally perceive an organic label as assurance that the product is organic. More accurately, organic food labels help transform the credence characteristics of such products into search attributes, thereby allowing the consumer to better evaluate quality before deciding to buy the product[20]. Thus, deceptive or inaccurate labeling can convey the wrong signals to prospective buyers.

It is important to note that knowledge and awareness about organic products may not necessarily translate into direct purchase because of barriers that could limit the ability of consumers to transform such knowledge and perceived demand into actual demand. This is partly because many potential organic consumers, especially in Western industrialized countries, are skeptical about organic labels[18]. Furthermore, in regions of the world where the organic agriculture sector is not yet well developed, and the process of organic certification and standardization is not uniform, few truly believe in the organic label[54]. Thus, although informed consumers may want to purchase organic products, skepticism about the true organic attributes may hold them back from doing so.

Consumer knowledge and awareness will continue to be important in the organic food market in two respects. First, there is still a segment of the potential market that is not yet informed about organic foods. For example, in a US study which reported that lack of knowledge and awareness was considered the number one reason why consumers do not buy organic food, 59% of respondents indicated that they never considered organic products because they did not know about them[55]. A second dimension to the knowledge and awareness puzzle is the possibility that those who do not consider organic products may have a general knowledge about them, but do not have enough detailed information to clearly differentiate the unique attributes of organic from conventionally grown alternatives.

In summary, knowledge and awareness about organic products can affect attitudes and perceptions and, ultimately, buying decisions. If the skepticism about organic products stemming, in part, from reported cases of mislabeling and fraud are assuaged, perceptions about the inherent characteristics of organic may translate into increased actual demand.

Characteristics of Organic Consumer Attitudes and Perceptions

Consumer actions regarding organic food stem from attitudes that, in turn, are linked to a complex set of ideas, motivations and experiences. Perceptions about particular attributes of an organic food can influence a buyer's choice because, according to Lancaster[21], consumer demand is linked to the characteristics inherent in economic goods. Studies on consumer perceptions about organic versus conventionally produced foods therefore attempt to determine

what consumers think is true. By comparison, consumer attitudes are likes and dislikes. That is, the positive or negative orientations toward organic or conventionally grown food. Consumer preference for a particular product is based on attitudes toward available alternatives[56]. Thus, if consumers are asked to indicate their preference for organically versus conventionally produced food, such respondents typically compare their attitudes toward the methods of producing the goods, and/or the product characteristics under consideration, before stating their preferences. Although particular attitudes are often assumed to lead to specific behaviors, the food and nutrition science, and social-psychological, literature provides limited evidence to support this assumption[24,57]. Overall, the scholarly literature suggests that various consumer attitudes work in contrasting ways—for and against purchasing organic products[24].

A general perception that, compared to organic production, conventional production systems tend to have long-term health implications and adverse effects on the environment has led some consumers to shift from conventionally to organically produced alternatives[44]. For example, food scares have spanned several years, including (using the UK as an illustration): typhoid fever in the 1960s; problems of mercury in fish, botulism in tinned salmon and hormone residues in veal and beef in the 1970s; salmonella in the 1980s; bovine spongiform encephalopathy (BSE) and *E. coli* in the 1990s; and foot-and-mouth disease in 2000s[1]. In North America, recent cases of BSE, as reported in northwestern US and western Canada, and avian flu in poultry are still fresh in the memories of most consumers, particularly in the affected areas. Such food scares have not only heightened consumer concerns and perceptions, but also raised questions about consumer confidence with government food regulatory agencies.

Key findings from selected studies on consumers' attitudes and perceptions about organic foods[57–69] are summarized in Table 2. Overall, most studies report that consumers purchase organic foods because of a perception that such products are safer, healthier and more environmentally friendly than conventionally produced alternatives. Some studies reported health and food safety as the number one quality attribute considered by organic produce buyers[3,24], followed by concern for the environment[1,28], suggesting that such consumers might rank private or personal benefits higher than the social benefits of organic agriculture.

Given that most of the studies relate to particular geographical areas and conditions, the extent to which the findings from such studies can be generalized is limited. Location-specific studies are sometimes criticized for representative sample problems: respondents sampled are typically limited to a particular location(s) or food store(s). Several of the studies are also very general in nature; i.e., without reference to specific organic products or groups of products and, therefore, do not allow for drawing useful conclusions about differences among particular products. A review of the available studies also showed little consistency across countries, in terms of consumer perceptions about organic product attributes.

The findings from some studies provide useful (background) information for future consumer and policy research. For example, Werner and Alvensleben[62] found that in Germany, organic fresh fruits and vegetables constitute a greater proportion of the consumers' food basket. By comparison, the most frequently purchased organic foods in a study in three California counties, in decreasing order of magnitude, were fruits, vegetables, chicken, eggs, and beef and pork products[22]. According to Hay[57], Canadians tended to buy more organic fruits and vegetables than any other category of organic products. Similarly, O'Donovan and McCarthy[63] found that vegetables were the most popular organic food group purchased in Ireland, where 53% of respondents reported consuming organic vegetables, compared to 45% for organic fruits.

Importance of factors that influence consumer preference

As noted earlier, consumer preference for organic food is based on a general perception that organic products have more desirable characteristics than conventionally grown alternatives. Apart from health, food safety and environmental considerations, several other product characteristics, such as nutritive value, taste, freshness, appearance, color and other sensory characteristics, influence consumer preferences[9].

Several studies have investigated the effect of organic quality attributes and other characteristics on consumer preferences[3,26,45,48,57,61,64–67]. These studies differ in several respects, making comparison across studies difficult. For example, there is inconsistency in defining the concept of quality. Thus, while some studies examined quality in terms of both sensory and nutritive characteristics, others differentiate sensory characteristics from nutritive attributes. Different studies may therefore convey different notions of quality to the various survey respondents.

Overall, the empirical evidence supports a hypothesis that product quality characteristics affect consumers' preferences for organic food, with the most important being: (1) nutritive value; (2) economic value; (3) freshness; (4) flavor or taste; (5) ripeness and (6) general appearance (especially of fruits and vegetables). Wolf[48], for example, reported that respondents in California rated fresh-tasting and fresh-looking grapes as the most desirable attributes. Other North American surveys that ranked taste as the most important quality characteristic influencing consumer demand include The Packer[68] and Demeritt[55]. The Packer[68] reported that 87% of US respondents identified taste as the primary factor considered in the purchase of fresh produce. In contrast, studies for other parts of the world[14,22,64] reported that consumers ranked nutritional value and freshness higher than taste and other related quality characteristics. This suggests that relative ranking of the attributes

Table 2. Summary of key findings from selected studies on organic consumer attitudes and preferred quality attributes.

Author(s)	Major conclusions
North America[1]	
Jolly et al.[22]	Food safety and nutritive value were rated as very important factors among 80% of respondents
Goldman and Clancy[24]	Consumers who usually buy organic food tended to be more concerned about food safety than price
Wolf[48]	Attributes that were 'very desirable' or 'extremely desirable' to organic consumers included: freshness, fresh-tasting, appearance, seedless, economic value or price, healthiness, high in nutritive value, free of insects and free of pesticides
Demeritt[55]	Respondents rated health/nutrition (66% of respondents), taste (38%), food safety (30%), environment (26%), product availability (16%), price (16%), appearance (12%) and family (11%) as factors that influenced organic choices
Hay[57]	Consumers of organic food appreciate the quality of the organic food and perceived them to be better in taste, quality, health and nutritive value
Baker and Crosbie[59]	Extent of product damage was the most important criterion used in assessing consumer food safety and preference
The Packer[61]	Taste was the most important food quality attribute that affected consumer's preference. 65% of respondents were concerned about chemical residues on fresh produce
Buzby and Skees[64]	The most important factors consumers used in judging food health and safety were fat levels, contamination and absence of pesticide residue. Freshness and nutritive value were the most important factors considered in organic-buying behavior
Huang[66]	Organic consumers were more concerned about pesticide residues and nutritive value, and less so with environmental stewardship
The Packer[68]	Appearance was the primary product attribute considered when shopping, usually followed by color and price
Western Europe	
Schifferstein and Oude-Ophuis[3]	Food quality (i.e. appearance), absence of chemicals, environmental friendliness, and taste were the most important factors that affect organic food demand
Grunert and Juhl[6]	Positive attitude towards environmental issues were found to be positively correlated with buying organic, and frequency of organic food purchases
Wandel and Bugge[7]	Majority of respondents ranked freshness first, followed by taste, and then nutritive value
Davies et al.[8]	The most commonly reported considerations for choosing organic produce were concern for the environment, and then health reasons. Availability and price were the main factors influencing actual purchase of organic produce
Torjusen et al.[14]	62% of respondents indicated they buy organic because it is perceived to be more healthy, while 67% purchase organic because of environmental considerations. Aspects of food that were more important to 70% of the consumers relate to quality characteristics
Ekelund[58]	The primary motivation for buying organic was for health reasons (i.e., absence of contaminants and chemicals)
Hutchins and Greenhalgh[47]	93% of respondents reported buying organic produce because of health reasons and/or because it is better for children. Less than 30% preferred organic because it is better for the environment
Øystein et al.[50]	Half of Norwegian respondents reported that organic food is more healthy, compared to 48% from France
Hack[60]	The primary reasons for buying organic products were linked to human health and environment considerations
Werner and Alvensleben[62]	Young people in Hanover, Germany tend to buy organic food (i.e., bakery products and cereals) more frequently, and less so for fruits and vegetables
O'Donovan and McCarthy[63]	Food safety was most important for meat consumers. Organic meat buyers believed the meat to be superior in terms of quality, safety, labeling, production methods and value
Kyriakopoulos and Oude-Ophuis[67]	Food quality is more important than price
Sandalidou et al.[69]	Health concerns were the most important factor influencing the purchase of organic olive oil. Important olive oil quality attributes considered were color, taste and flavor
Rest of the world	
Wang et al.[54]	About 76% believed that organic foods are safer than conventional alternatives, while 9% of respondents believed that foods labeled organic were truly organic
Aguirre[65]	100% of organic consumers indicated they buy organic because of health concerns, compared to 95% for environmental concerns

[1] North America refers to USA and Canada only.

that consumers prefer varies depending on the actual product[69], and across regions (partly due to cultural and other factors that are difficult to control for in surveys). What seems clear, and consistent across studies, is that consumers across all regions tend to prefer locally grown organic produce, compared to shipments from other places.

In addition, it appears that among existing organic consumers, preference for organically grown foods tends to be influenced more by product quality and other inherent product characteristics, than by price premium[6]. On the other hand, several studies reported that price premium, lack of knowledge and product availability were the major reasons preventing nonbuyers from purchasing organic food[50,55,63–70]. Demeritt[55], for example, reported that the most important reason why US consumers did not purchase organic food was lack of knowledge or awareness. About 59% of those who did not purchase organic products indicated they never really considered organic, while 39% indicated that price was the main inhibiting factor. Another 16% reported that they did not purchase organic food because of limited availability. Some studies for the UK[63,70] also cited product availability and price as key factors that hamper consumer demand for organic foods. For example, Davis et al.[8] reported that two-thirds of nonbuyers of organic food in Ireland indicated they would buy organic if it was easily available. By comparison, O'Donovan and McCarthy[63] reported that among Irish respondents who did not purchase organic food, 43% indicated that it was too expensive, 28% cited lack of availability, while 29% were just not interested.

Price and Willingness-to-pay for Organic Products

The willingness-to-pay (WTP) for particular food attributes is linked to an observation that consumers make trade-offs for improved attributes in products[2]. A WTP also reflects an observation that individual preferences are unique[71]. Given that yields are generally lower for organic production than for conventional production, consumer willingness-to-pay a price premium for organic products is an important determinant of organic farm profitability and long-term financial sustainability. Magnitude of the price mark-up can also provide useful information about the value consumers place on particular product attributes. A price premium on organic produce can signal differences in product attributes and characteristics and, therefore, is an important search attribute for hedonists. In addition, as indicated earlier, environmentalists may be willing to pay price premiums to support local organic producers. Yet, long-term time-series on organic market price data are limited. Thus, although important insights can be gained from the early studies on price mark-ups for organic products, caution should be exercised in drawing definite conclusions from analysis using such limited time-series data.

Several studies in North America suggest that groups of consumers are willing to pay price premiums for organic products[24,45,48,57–59]. Similar results have been found for the European Union (EU), and other regions of the world[7,62,63]. The key findings from selected studies, including details of premium levels consumers are willing to pay[72–75], are summarized in Table 3, for general and specific organic foods. Jolly[74], for example, found that US consumers were willing to pay a 37% price premium for organic products. By comparison, Goldman and Clancy[24] reported that a third of respondents in a New York survey were willing to pay a 100% price premium for a residue-free product. In the EU, Ekelund[58] reported that about 55% of respondents in Sweden were willing to pay 25% above a regular, conventionally grown product price, with another 26% of organic buyers willing to pay 50% more. A study of consumers in the UK also reported that buyers were willing to pay a price premium of up to 30%[47].

The findings from the literature allow us to make several conclusions. First, consumers tend to be willing to pay higher price premiums for organic products with a shorter shelf life, such as fruits and vegetables, compared to cereals. For example, Millock and others[72] reported that 59% of respondents in Denmark were willing to pay a price premium of 32% for organic milk, 41% of respondents indicated a WTP 40% extra for organic potatoes, 51% were willing to pay a price premium of 23% for organic rye bread, and 41% indicated they would pay 19% extra for minced organic meat.

Secondly, the proportion of respondents willing to pay a price premium decreases as the premium level increases. In addition, premiums tend to increase with (combinations of) preferred attributes. Thirdly, what is not clear, and is in need of investigation, is whether frequent buyers consider particular organic products (e.g., organic meat) as normal goods, or if such consumers consider them as luxury goods. Fourthly, based on the studies reviewed, there are no clear differences or patterns across countries, and comparisons are complicated by differences in study methods. For example, a number of studies investigated generic, as opposed to, specific organic products.

Overall, most consumers are not willing to pay a price premium above 10–20%. In other words, demand for organically grown food declines sharply with premiums above 20%[73]. Yet analysis of specific organic food markets for selected countries[76] suggests that there are substantially high actual price mark-ups. Turco[76] reported organic price premiums ranging from 10% to as high as 100%, depending on the country (Table 4). For example, organic price premiums for different types of products in Italy ranged from 35 to 100%. By comparison, price premiums reported in Turkey ranged from 43% for pickled vine leaf, to as high as 468% for mixed dried fruits[77], while premiums in Canada ranged from 14% for apples, to 174% for pork chops[76].

Price elasticity of demand for organic products is a related aspect of consumer willingness-to-pay. Organic produce retailers tend to be quite sensitive to consumers' price elasticity of demand, partly because premium level negatively affects consumer demand and purchases.

Table 3. Summary of key findings from selected studies on consumer willingness-to-pay a price premium for organic products.

Author	Key findings
North America[1]	
Goldman and Clancy[24]	Respondents at a food cooperative indicated a WTP a 100% price premium for organic foods in general
Wolf[48]	30% of respondents reported a WTP a 50% price premium for organic grapes
Hay[57]	Consumers indicated a WTP a price premium of not more than 25% for organic products in general
Buzby and Skees[64]	Majority of respondents reported a WTP between 15 and 69 cents above the 50 cents a unit for grapefruit for reduced pesticide residue. Another 5% of consumers indicated they would pay more than double the price of regular fresh grapefruit for a safer one
Jolly[74]	Consumers indicated a WTP a 37% premium for organic horticultural products
Ott[75]	66% of respondents were willing to pay a 10–15% price premium for pesticide-free fresh produce
Western Europe	
Wandel and Bugge[7]	70% of respondents reported a WTP an extra 5% for organic fruits, vegetables, potatoes and meat. Only 10% of respondents were willing to pay a 25% price premium for the same products
Ekelund[58]	55% of respondents indicated a WTP a 25% price premium, with another 26% willing to pay a 50% premium for organic vegetables
Hutchins and Greenhagh[47]	Consumers reported a WTP a 30% price premium, especially for organic cereals, fruits and vegetables
Werner and Alvensleben[62]	About 93% of frequent buyers of organic food were willing to pay a price premium of 29%. By comparison, 69% of occasional buyers were willing to pay a price premium of 27%, and 21% of nonbuyers reported they were willing to buy in the future at a premium of 27%
O'Donovan and McCarthy[63]	About 70% of consumers were not willing to pay more than 10% price premium for organic meat
Millock et al.[72]	51% of respondents indicated a WTP a 23% price premium for rye bread; 59% were willing to pay 32% extra for organic milk; 41% were willing to pay 40% premium for organic potato; and 41% were willing to pay 19% premium for organic minced meat
Soler et al.[73]	70% of respondents indicated a WTP a price premium for organic virgin olive oil
Rest of the world	
Wang et al.[54]	About 80% of respondents indicated a WTP a price premium of 5% or more, and 50% of these were willing to pay a price premium of 5–10%
Aguirre[65]	The majority of respondents reported a WTP at least 10% more for organic products

[1] North America refers to USA and Canada only.
WTP, willingness-to-pay.

Demand tends to depend more on the price differential with respect to conventionally grown products than on absolute price[23]. In general, although both buyers and nonbuyers consider organic as expensive, nonbuyers perceive organic price as too expensive[6]. Some econometric studies have reported high negative price responses to organic food demand[40,70,73]. In an analysis of the organic produce market in Denmark, Wier et al.[78] found a high own-price elasticity of demand (i.e., sensitivity of demand to a change in the price of the same, as opposed to a related, product) for dairy products (−2.3). Results from econometric testing of the frozen organic pea market in the US also support the high negative price/quantity relationship[78]. The relatively high own-price elasticities suggest that consumers are quite sensitive to organic product price changes, compared to those of conventionally grown alternatives.

Who is the Organic Consumer?

Studies that have investigated the profile of organic consumers have examined how socio-economic and demographic factors influence willingness-to-pay for organic products[49,57,59,62,66,74]. In contrast to the findings on price elasticity, income elasticity of demand for organic produce is generally small and not statistically significant[79] or zero[24], although there are exceptions to this general finding[80]. Most studies report that income is not a significant variable in explaining differences in the purchasing behavior of buyers and nonbuyers of organic products[45]. Further insight on the effect of income on organic food demand is highlighted in studies in Canada which suggest a positive correlation between income and willingness to buy a product, up to a given level of income, beyond which further increases in income do not lead to a corresponding increase in willingness to purchase organic food[47,58].

Most buyers of organic foods tend to be women[63,64,70], partly because they are usually the primary grocery shoppers in most households and, consequently, tend to be more informed about nutrition and food safety than men[79]. On the other hand, Wandel and Bugge[7] suggest that men were more willing to pay a higher price premium for organic products than women. Attempts at explaining the relationships in the various findings are complicated by interlinked economic (e.g., household income levels), demographic (e.g., number of young children in family) and other variables (e.g., knowledge of organic).

Most studies suggest a negative relationship between age and organic buying behavior. An exception is Jolly[45], who

Table 4. Comparison of price premiums for organic foods, selected countries (source: Turco[76]).

Market	Price premium over comparable conventional food (%)
Australia	20–40
Austria	25–30
Denmark	20–30
France	25–30
Italy	35–100
Germany	20–50
Netherlands	15–20
Sweden	20–40
Switzerland	10–40
United Kingdom	30–50
Japan	10–20
United States	10–30

found no correlation between age and organic buying behavior. Studies reporting that younger consumers are more likely to purchase organic products attributed this to their (i.e., younger consumer) preference for chemical-free products and interest in environmental quality[57,64]. Hay[57], for example, reported that younger Canadians tended to have a higher preference for chemical-free products and tended to prefer organic products, compared to older consumers who tended to be less concerned with complete elimination of chemicals. In contrast, Bhaskaran and Hardley's[81] hypothesis that older consumers (i.e., more than 55 years) tend to make preventive health decisions, partly because of perceived health vulnerability and an awareness that they are generally at higher health risk than younger individuals, is consistent with the findings of Jolly[45]. Many individuals with higher educational achievements tend also to have higher incomes. Therefore, without controlling for this, it is not clear whether such a correlation makes one of the two variables redundant in studies that examined the relationship between level of education attained and organic buying behavior.

Summary and Conclusions

A growing interest in organic agriculture has prompted numerous studies comparing aspects of organic and conventional agriculture. This study consolidated and reviewed numerous studies involving various products and several (developed and developing) countries. A consumer-based approach to understanding organic agriculture, involving such a comprehensive evaluation, is useful not only in helping to better understand changing organic market dynamics, but also for organic consumer demand modeling and estimation, and market analysis.

Our human conception of consumer decision making and behavior towards organically grown products is consistent with an economic notion that consumers demand the characteristics inherent in such products. The quality characteristics of organic food constitute inputs into a consumer's demand function for improved (human) health and overall well-being. The price premium on organic food can be viewed as the cost of investment in human health. Product prices also provide signals about the inherent quality characteristics of a product, as well as reflecting the value of inputs used to produce the product.

Although the literature suggests some consumer knowledge and awareness, consumers (sometimes within the same country) are not consistent in their interpretation of what is organic. Some skepticism about the true attributes of organic and organic labels, part of which stems from reported cases of mislabeling and product misrepresentation, and partly because of nonuniform organic standards and certification procedures, may hold some consumers back from purchasing organic.

Human health, food safety and environmental stewardship, along with several other product characteristics (such as nutritive value, taste, freshness, appearance and other sensory characteristics) influence consumer preferences. Eliciting consumer preference for organic (versus conventionally grown) products is typically based on a comparison of consumer attitudes toward the production systems used and (perceived and actual) product characteristics. Consumer preference for organic food is based on a general perception that such organic foods have more desirable characteristics than conventionally grown alternatives. Overall, there is no consensus regarding the relative importance of the organic food quality attributes (such as human health, food risk and safety, and environmental considerations) that affect consumer attitudes and perceptions. In addition, across all regions of the world, consumers tend to prefer locally grown produce to shipments from other areas.

A willingness to pay a price premium for organic products is important for farm financial sustainability. Yet, long-term time-series price data for the organic sector are limited. Thus, while important insights can be gained from studies on willingness to pay price premiums, caution should be exercised in drawing definite conclusions from studies using such limited data. In general, the proportion of respondents willing to pay a price premium decreases as the premium increases, while premiums tend to increase with (combinations of) preferred attributes. The literature does not provide a clear pattern about the levels of price premiums various groups of consumers are willing to pay, nor which group(s) of products attract high mark-ups. Own-price elasticity of demand is relatively higher for organic products, partly because organic products tend to vary widely in appearance and are limited in supply during particular seasons. In addition, demand for organic products tends to depend more on the price differential relative to conventionally grown alternatives, than on actual price. In contrast to the effect of price on organic product demand, income elasticity of demand for organic products is small. The effects of socio-economic and demographic

variables on organic consumer preferences and purchase behavior are complicated by inherent correlations among particular variables (e.g., education and income levels) and, therefore, need to be controlled for to provide a better understanding of causal relationships.

Fresh fruits and vegetables tend to dominate the current market food basket of the organic consumer. On the other hand, based on the studies reviewed, it is not clear whether frequent buyers consider organic products (such as organic meat) as normal goods, or if buyers consider such food products as luxury goods. Empirical evidence of the relationship between particular organic foods and consumer income will not only help to better understand how consumers really perceive the quality and safety attributes of organic products compared to their conventional alternatives, but will also have implications for organic product demand as average income levels increase (with economic growth).

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Organic cucumber production in the greenhouse: A case study from Turkey

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Abstract

Organic farming seems to be a solution in environmentally sensitive zones such as the protection zone of Tahtalı Dam, which supplies fresh water to Izmir, the third largest city in Turkey. Greenhouse vegetable production is the major agricultural activity in this area (Menderes Township). However, due to the pollution risk from agriculture, governmental authorities have issued a regulation discouraging the use of chemicals within the collection basin of the dam. An on-farm project was conducted in 2001 to introduce organic greenhouse vegetable production in the Tahtalı Dam preservation area and to serve as a model for other areas in Turkey facing similar ecological problems. Two irrigation levels and four organic fertilizers were tested on the growth of cucumbers (*Cucumis sativus* cv. Sardes). The four fertilizers were two rates of farmyard and poultry manure (30 and 50 tons ha^{-1}) with and without two organic fertilizers based on either bacteria or algae. During the growing period, pests and diseases were monitored weekly and preparations allowed in organic agriculture were used when necessary. Plant diseases did not create any significant problem, but the pest population, in particular spidermites, increased. No significant differences in cucumber yield were found between the fertilizer and irrigation treatments tested. However, it should be noted that yields from the addition of 30 tons ha^{-1} of farmyard or poultry manure and organic fertilizers were the same as those for 50 tons ha^{-1} of manure alone. The average total yield was 13 kg m^{-2}, within an acceptable range for short-term crop production in this region, but 55% lower than a conventional substrate culture trial nearby. However, due to reduced production costs and a price premium for organic products, the organic produce yielded a net return of US$1.12–1.79 per m^2 whereas that for conventional bag culture produce was US$0.55 per m^2. Our results indicate that, under present conditions, organic greenhouse cucumber production has less environmental impact and is more economic than conventional bag culture, due to reduced chemical input and reduced operating and initial investment costs.

Key words: irrigation, organic fertilizer, farmyard manure, poultry manure

Introduction

Increasing populations in urban areas have an impact on agriculture, both in terms of land-use management and in terms of pollution created. In the case of Tahtalı Dam, which is the major water source providing drinking water to Izmir, the third largest city in Turkey, the problems seem to be multifaceted[1]. A preservation area was established around the lake in order to prevent pollution, and restrictions were imposed by the state in respect to irrigation, fertilization and pesticide use.

Within the preservation area of the Tahtalı Dam, greenhouse production is the most important agricultural activity. This production is realized under prevailing climatic conditions in very simple structures, therefore problems are frequent and complicated, and, thus, synthetic chemicals are used intensively, as in other Mediterranean countries. The introduction of environmentally friendly systems could be a solution for sustaining agricultural practices in an economically feasible way and maintaining a healthy balance between agricultural land and environment[2].

Organic farming is one of several approaches to sustainable agriculture, and organic greenhouse vegetable production has potential as a niche market for out-of-season produce[3], excluding the use of synthetic fertilizers, pesticides, growth regulators and transgenic seeds. Organic producers rely heavily on crop rotations, crop residues, animal manures, legumes, green manures, organic wastes and mineral-bearing rocks to fertilize the soil and supply plant nutrients. Insects, weeds and other pests are managed

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by mechanical cultivation, and cultural, biological and biorational controls[4,5].

The purposes of this study were to introduce organic greenhouse vegetable production as an on-farm trial in the preservation area of Tahtalı Dam; to evaluate the effects of different organic fertilizers and irrigation schedules on yield, and to determine the costs and returns associated with organic cucumber production under greenhouse conditions.

Material and Methods

The experiment was conducted in Menderes, within the long-range protection zone of Tahtalı Dam, as an on-farm trial in 2001 in a polyethylene (PE)-covered greenhouse (12×32 m) erected with galvanized steel hoops, with side and roof ventilation and covered with insect net.

The experimental design was split-plot with three replicates. The main plots were assigned to two irrigation levels (I) and the subplots to four organic fertilizers (F). The data related to the analysis of irrigation water and the physical and chemical properties of the poultry and farmyard manure are given in Table 1. Irrigation was programmed according to the soil moisture tensions of 0.03 MPa and 0.05 MPa, corresponding to treatments I_1 and I_2, respectively. The tested fertilizer applications were composed of farmyard manure, 30 tons ha^{-1} + E 2001 + Allgrow Bioplasma (F_1); farmyard manure, 50 tons ha^{-1} (F_2); poultry manure, 30 tons ha^{-1} + E 2001 + Allgrow Bioplasma (F_3) and poultry manure, 50 tons ha^{-1} (F_4). Two commercial organic fertilizers, one with bacteria, E 2001 (Agricultural Research Technologies Ltd., Bonham, USA), and one based on algae, Allgrow Bioplasma (Biotech Industry AB, Stockholm, Sweden) were selected in order to promote microorganism activity in the soil. E 2001 was applied a week prior to planting at 300 ml $plot^{-1}$. Allgrow Bioplasma was applied to the soil three times—just after planting and on 15 and 21 April 2001 (200 ml $plot^{-1}$), and to the foliage on 4 May 2001 (150 ml $plot^{-1}$).

Irrigation timing and water quantity in each treatment (0.03 and 0.05 MPa) were programmed automatically, using electronic tensiometers placed in the soil at a depth of 20 cm. Additionally, readings of soil moisture tensions were monitored at 20 and 45 cm depths of soil, in order to control soil moisture level in the effective plant root zone at tensions of 0.03 and 0.05 MPa.

Cucumber (*Cucumis sativus*) seedlings were planted on 29 March 2001 with a plant density of 1.85 plant m^{-2} ($1.2 \times 0.6 \times 0.6$ m). The cultivar was Sardes, which is resistant to powdery mildew (PM), cucumber mosaic virus (CMV), cucumber vein yellowing virus (CVYV) and zucchini yellow mosaic virus (ZYMV).

Soil solarization, a hydrothermal disinfection method, was applied for 4 weeks in summer in order to eliminate soilborne pathogens. This practice is based on covering the water-saturated soil with a transparent polyethylene sheet, and, thus, increasing the soil temperature by the solar energy.

Table 1. Physical and chemical properties of manures and the water quality.

	Poultry manure	Farmyard manure
pH	9.00	9.10
Soluble total salts (%)	2.11	1.92
Organic matter (%)	32.06	34.13
Total carbon (%)	18.60	19.80
Total nitrogen (%)	1.05	1.11
C/N	17.71	17.84
Total phosphorus (%)	1.17	0.76
Total potassium (%)	1.70	1.50
Total calcium (%)	8.00	7.47
Total magnesium (%)	0.92	0.76
Total sodium (%)	0.40	0.18
Total iron (%)	2.14	1.62
Total copper (mg kg^{-1})	48.10	1.62
Total zinc (mg kg^{-1})	289.50	294.00
Total manganese (mg kg^{-1})	467.20	93.10
	Water quality	
Cations		
Na^+ (me l^{-1})[1]	1.10	
K^+ (me l^{-1})	0.05	
$Ca^{2+} + Mg^{2+}$ (me l^{-1})	5.90	
Total (me l^{-1})	7.05	
Anions		
Cl^- (me l^{-1})	1.10	
CO_3^{2-} (me l^{-1})	–	
HCO_3^- (me l^{-1})	5.25	
SO_4^{2-} (me l^{-1})	0.79	
Total (me l^{-1})	7.14	
SAR	0.64	
Class.	C2S1	

[1] (me l^{-1}) = milliequivalents per liter (centimoles per liter).
C/N, carbon/nitrogen ratio; SAR, sodium absorption ratio; Class., classification.

Fruit samples were taken three times (25 May 2001, 25 June 2001 and 17 July 2001) during the harvest period in order to determine some fruit quality parameters, namely fruit color, average fruit weight, diameter, length and firmness, total soluble solids (TSS), titratable acidity (TA) and dry matter content. Five fruit samples were taken for each plot. Fruit color was measured with a Minolta CR 300 tristimulus chromameter (Konica Minolta Sensing Inc., Tokyo, Japan), consisting of a head with an 8 mm diameter measuring area, as CIE $L*a*b$ values, where L shows lightness; a, the red–green and b, the yellow and blue axes of XY color coordinates, indicating color directions. At least six measurements were taken from each fruit, on both ends and the middle. The chromameter was calibrated using the manufacturer's standard white tile prior to measurements, and the color is expressed as lightness, chroma ($\sqrt{a^2+b^2}$) and hue° [$\tan^{-1}(b/a)$] values. Fruit firmness was measured on each fruit with an Effe-Gi penetrometer (Effe-Gi, Alfonsine, Italy), using the standard 7.94 mm diameter

Table 2. Preparations applied against pest and diseases in cucumber production.

Date	Application	Pest	Dose (%)
16 April 2001	NeemAzal T/S	Leafminer	0.5
26 April 2001	Sulfur	Powdery mildew	0.4
01 May 2001	Sulfur[1]	Spidermite	0.4
07 May 2001	Sulfur[1]	Spidermite	0.4
22 May 2001	Sulfur	Spidermite	0.4
29 May 2001	Herba Vetyl	Spidermite	0.1
04 June 2001	Potassium soap	Spidermite	3.0
12 June 2001	Potassium soap	Spidermite	3.0
18 June 2001	Potassium soap	Spidermite	3.0
25 June 2001	NeemAzal T/S	Spidermite	0.5
02 July 2001	NeemAzal T/S	Spidermite	0.5
05 July 2001	Sulfur	Powdery mildew	0.4
09 July 2001	Sulfur	Spidermite	0.3
12 July 2001	Organica neem oil	Spidermite	2.0

[1] Local application on plants close to the entrance of the greenhouse.

probe and expressed as Newtons. Fruit juice was extracted using a kitchen juicer, and filtered through qualitative paper. Total soluble solid content was measured by a digital refractometer (Euromex RD 645, Arnhem, The Netherlands). Titratable acidity was determined by titration with 0.1 *N* NaOH until pH 8.1 and expressed as mval 100 ml^{-1}. The dry matter content (expressed as the percentage of fresh weight) was determined by drying samples in an oven at 65°C until constant weight was obtained. The means of three sampling periods were used for statistical analysis.

To study changes in the physical and chemical properties of the experimental site, soils were sampled twice, on 2 April and 16 July 2001.

During the growing period, observations were made twice a week in order to determine infection by pests and diseases. Above-ground pests were monitored by counting 80 leaves. Sticky yellow traps, 1 per 15 m^2, were hung 10 cm above the plants to monitor the pests, and changed at 2-week intervals. For nematode determination, soil samples were taken before and after the solarization and four times during the growing period, totaling six samples. Determinations were made according to Flegg and Hooper[6]. In addition, the roots of 50 plants were checked for nematode damage at the end of the growing season[7].

For pest and disease control, preparations permitted in organic agriculture were used when necessary, namely copper, sulfur, Organica neem oil, NeemAzal T/S (neem extracts), Herba Vetyl (natural pyrethrum extract), potassium soap. Copper (50% CuO) and sulfur (80% wettable) were applied as 0.4% and the rates of Organica neem oil, NeemAzal T/S, Herba Vetyl and potassium soap used were 2.0, 0.5, 0.1 and 3.0%, respectively, as recommended (Table 2).

Input costs, which included the variable, fixed and construction costs, were determined[8–10]. In this study, variable costs covered labor, fertilizer, seedling, electricity, certification, marketing, hauling, etc., using the current input prices and labor wages. Fixed costs included interest on total initial investment costs, annual initial investment costs, interest on total variable costs, administrative costs and land rent. Interest on total initial investment costs and total variable costs was calculated by charging a rate of 12%. (saving deposit interest rate on US$ for 2001 in Turkey). Total initial investment costs, annual initial investment costs and land rent were divided by two, since two harvests per year are possible in greenhouses. Administrative costs were estimated to be 3% of total variable costs. Depreciation was estimated using the straight-line method. Assets were divided by their useful life expectancies to determine annual costs for depreciation. The greenhouse is exempted from property tax and wasn't insured. Fixed costs plus variable costs equal total production costs. In this study, total costs were subtracted from total gross revenue to calculate the net return.

Data related to yield, quality and nutrient elements were subjected to analysis of variance (ANOVA) using SPSS software (SPSS Inc., Chicago, Illinois, USA). Means were compared with Fisher's protected least significant difference (LSD) test at $P \leq 0.05$.

Results

Yield

Harvests started on 6 May and continued until 18 July 2001. Effects of the irrigation treatments and organic fertilizers were found to be insignificant. The total yield varied between 6.17 and 7.57 kg plant^{-1}, and average yield was determined as 7.01 kg plant^{-1} (Table 3).

Fruit quality

The irrigation programs and organic fertilizers had impacts on some of the assessed quality parameters. For example, the effect of irrigation programs on titratable acidity and color was significant. The titratable acidity increased in the second irrigation program (I_2), probably due to the decrease in the amount of applied water (Fig. 1). Although the irrigation program did not have a statistically significant effect on fruit firmness and total soluble solids, these parameters were enhanced as the amount of applied water decreased. The color of the fruits obtained from the plots of the second irrigation program were darker than those of the

Table 3. Changes in total yield (kg plant^{-1}) according to the treatments.

	FYM + 2001 + Bio	FYM	PM + 2001 + Bio	PM	Mean
I_1 (0.03 MPa)	6.42	7.57	7.54	7.28	7.20
I_2 (0.05 MPa)	6.17	6.47	7.30	7.35	6.82
Mean	6.30	7.02	7.42	7.32	

FYM, Farmyard manure; 2001, bacterial fertilizer E 2001; Bio, Allgrow Bioplasma; PM, poultry manure.

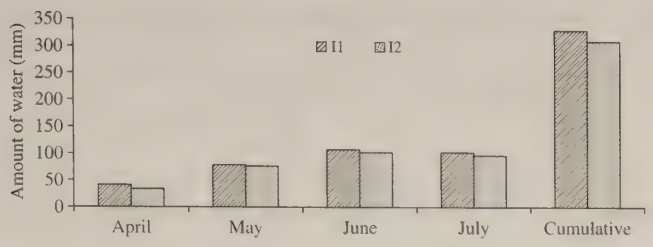

Figure 1. Amount of water applied to the treatments (mm). Irrigation was programmed according to soil moisture tensions: I_1, 0.03 MPa; and I_2, 0.05 MPa.

first program. In this regard, organic fertilizers affected only the lightness and chroma values. Shinier and saturated green fruits were also darker in the farmyard manure applications, although the effect on hue angle was not statistically significant (Table 4).

Irrigation

The number of irrigations changed according to the treatments, being 29 and 16 in I_1 and I_2, respectively. The water requirement of the plants was lower at the beginning of the growing season, but the amount of water and irrigation intervals increased later, due to climatic conditions and plant development stage (Fig. 1). The total amounts of water applied to I_1 and I_2 were 329.6 and 308.9 mm, respectively.

Tensiometer readings placed at 20 cm depth were 0.03–0.035 MPa in I_1 and 0.05 MPa in I_2 before irrigation, and dropped to 0.02 MPa after irrigation in both treatments; whereas at 45 cm depth, tensiometer readings were 0.045 and 0.020 MPa before and after irrigation, respectively.

Soil fertility

Measured once at the initial stage (2 April 2001) and once at the end of the growing period (16 July 2001), the averages of pH, organic matter, total soluble salts and calcium carbonate for all treatments were 6.98, 1.10%, 0.124% and 0.88%, respectively. Available plant nutrients in the soils changed according to the sampling dates: N, 0.047–0.70%; P, 13.59–45.03 mg kg^{-1}; K, 97.5–428 mg kg^{-1}; Ca, 1671–2208 mg kg^{-1}; Mg, 190–265 mg kg^{-1}; Na, 57.7–124 mg kg^{-1}; Fe, 13.9–25.8 mg kg^{-1}; Cu, 2.83–3.78 mg kg^{-1}; Zn, 2.65–3.7 mg kg^{-1} and Mn, 15.3–24.3 mg kg^{-1} (for details, see Table 5).

Pests and diseases

Regarding the diseases, only powdery mildew (*Erysiphe cichoracearum*) was determined. Due to the sulfur treatments for spidermites (26 April, 22 May and 5 July 2001) and removal of the lower leaves, the damage was reduced.

Carmine spidermite (*Tetranychus cinnabarinus* (Boisd.) (Acarina, Tetranychidae)) and whitefly (*Bemisia tabaci*

Table 4. Changes in fruit quality parameters.

Irrigation programs[1]	Fertilizers	Lightness	Hue°	Chroma	Average fruit weight (g)	Fruit diameter (cm)	Fruit length (cm)	Fruit firmness (N)	TSS (%)	TA (mval 100 ml^{-1})	Dry matter (%)
I_1	FYM + 2001 + Bio	38.06	125.29	21.97	124.58	3.18	17.63	63.58	3.49	1.17	2.21
	FYM	37.45	125.61	20.78	120.70	3.13	17.63	61.42	3.68	1.24	2.36
	PM + 2001 + Bio	36.02	126.01	19.59	125.55	3.27	17.54	59.01	3.60	1.32	2.30
	PM	37.18	126.16	19.55	136.67	3.32	18.02	62.01	3.62	1.52	2.31
I_2	FYM + 2001 + Bio	36.77	125.90	20.13	122.50	3.23	16.95	76.62	3.53	1.43	2.19
	FYM	36.87	126.24	19.64	134.44	3.23	17.80	63.35	3.60	1.52	2.20
	PM + 2001 + Bio	36.60	126.33	19.16	138.06	3.33	18.05	65.93	3.68	1.49	2.21
	PM	36.81	125.94	19.57	131.39	3.27	17.62	58.77	3.65	1.45	2.11
	$LSD_{0.05}$ IP × OF	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
I_1	Average of 4 fertilizers	37.18	125.77	20.47	126.88	3.23	17.71	61.51	3.60	1.31	2.30
I_2	Average of 4 fertilizers	36.76	126.10	19.63	131.60	3.27	17.61	66.17	3.62	1.47	2.18
	$LSD_{0.05}$ IP	0.360*	0.195**	0.494**	ns	ns	ns	ns	ns	0.115*	ns
Average of I_1 and I_2	FYM + 2001 + Bio	37.42a	125.60	21.05ab	123.54	3.21	17.29	70.10	3.51	1.30	2.20
	FYM	37.16a	125.93	20.21a	127.57	3.18	17.72	62.39	3.64	1.38	2.28
	PM + 2001 + Bio	36.31b	126.17	19.38b	131.81	3.30	17.80	62.47	3.64	1.41	2.26
	PM	37.00ab	126.05	19.56b	134.03	3.30	17.82	60.39	3.64	1.49	2.21
	$LSD_{0.05}$ OF	0.749*	ns	1.059*	ns	ns	ns	ns	ns	ns	ns

[1] I = Irrigation programs; average soil water tension of 0.03 MPa (I_1) and 0.05 MPa (I_2).
IP, irrigation program; OF, organic fertilizer; TSS, total soluble solids; TA, titratable acidity; FYM, farmyard manure; 2001, bacterial fertilizer E 2001; Bio, Allgrow Bioplasma; PM, poultry manure.
LSD, least significant difference; values followed by the same lower-case letter are not significantly different at *, $P \leq 0.05$; **, $P \leq 0.01$. ns, not significant.

Table 5. Changes in soil physical and chemical properties and nutrients in the greenhouse between two sampling times (1, 2 April 2001; 2, 16 July 2001) for two irrigation and four fertilizer treatments.

		Irrigation level							
		I_1				I_2			
	Dates	Organic fertilizer treatment				Organic fertilizer treatment			
	Mean	FYM	FYM + 2001 + B	PM	PM + 2001 + B	FYM	FYM + 2001 + B	PM	PM + 2001 + B
Organic matter (%)	1	0.72	0.77	0.86	1.80	0.93	0.75	0.50	1.44
	2	1.11	1.17	1.01	1.14	1.41	1.20	1.86	0.92
	Mean	0.92	0.97	0.94	1.47	1.17	0.98	1.18	1.18
pH	1	6.93	6.81	6.78	6.80	6.91	6.89	6.82	6.82
	2	7.23	7.08	6.85	7.11	7.16	7.30	6.86	7.26
	Mean	7.08	6.95	6.82	6.96	7.04	7.10	6.84	7.04
Total salt (%)	1	0.12	0.12	0.115	0.12	0.085	0.062	0.085	0.14
	2	0.16	0.16	0.27	0.12	0.125	0.055	0.19	0.06
	Mean	0.14	0.14	0.193	0.12	0.105	0.059	0.138	0.1
$CaCO_3$ (%)	1	0.88	0.92	0.81	1.11	0.12	0.77	0.96	0.88
	2	0.98	0.67	1.03	1.16	0.67	0.76	1.29	0.98
	Mean	0.93	0.80	0.92	1.14	0.40	0.77	1.13	0.93
N (%)	1	0.042	0.039	0.044	0.085	0.047	0.035	0.030	0.070
	2	0.056	0.055	0.050	0.054	0.071	0.058	0.095	0.044
	Mean	0.049	0.047	0.047	0.070	0.059	0.047	0.063	0.057
K ($mg\,kg^{-1}$)	1	253.0	175.0	409.0	117.0	214.0	117.0	331.0	720.0
	2	175.0	117.0	175.0	97.0	136.0	78.0	272.0	136.0
	Mean	214.0	146.0	292.0	107.0	175.0	97.5	301.5	428.0
P ($mg\,kg^{-1}$)	1	33.69	16.85	–	33.29	16.95	13.64	21.06	70.1
	2	14.54	10.83	13.64	15.14	11.23	13.54	14.84	19.96
	Mean	24.12	13.84	13.64	24.22	14.09	13.59	17.95	45.03
Ca ($mg\,kg^{-1}$)	1	1432	2149	1969	1910	1671	1611	2029	1432
	2	1910	1969	2268	2149	1910	1796	2387	2268
	Mean	1671	2059	2118.5	2029.5	1790.5	1703.5	2208	1850
Na ($mg\,kg^{-1}$)	1	63.44	80.74	80.74	57.67	92.27	57.67	69.2	126.87
	2	132.64	138.41	167.24	109.57	115.34	57.67	138.41	51.9
	Mean	98.04	109.58	123.99	83.62	103.81	57.67	103.81	89.39
Mg ($mg\,kg^{-1}$)	1	240	220	200	230	190	280	220	180
	2	210	190	240	240	190	250	160	220
	Mean	225	205	220	235	190	265	190	200
Fe ($mg\,kg^{-1}$)	1	22.3	25.4	22.1	26.6	21.8	25.4	19.8	14.4
	2	28.9	22.3	19.8	22.1	22.0	26.2	16.3	13.4
	Mean	25.6	23.85	20.95	24.35	21.9	25.8	18.05	13.9
Cu ($mg\,kg^{-1}$)	1	3.12	2.98	3.12	3.21	3.12	3.9	3.28	2.98
	2	2.82	2.78	2.89	3.03	2.99	3.65	3.04	2.67
	Mean	2.97	2.88	3.01	3.12	3.06	3.78	3.16	2.83
Zn ($mg\,kg^{-1}$)	1	4.0	3.0	3.9	3.8	3.0	3.5	2.9	2.9
	2	3.4	2.3	3.4	3.3	2.4	3.6	2.9	2.8
	Mean	3.7	2.65	3.65	3.55	2.7	3.55	2.9	2.85
Mn ($mg\,kg^{-1}$)	1	18.89	16.49	24.59	20.98	21.44	22.85	16.32	16.89
	2	17.32	13.89	24.06	16.89	18.56	19.98	14.32	14.59
	Mean	18.11	15.19	24.33	18.94	20	21.42	15.32	15.74

FYM, farmyard manure; 2001, bacterial fertilizer E 2001; B, Allgrow Bioplasma; PM, poultry manure.
Irrigation programs: average soil water tension of 0.03 MPa (I_1) and 0.05 MPa (I_2).

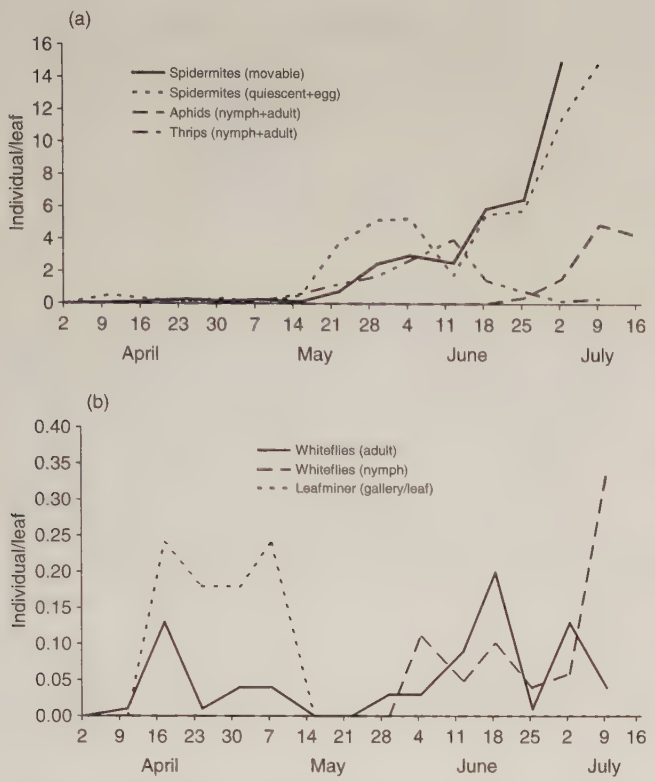

Figure 2. Population densities of pests in cucumber production: (a) spidermites, aphids and thrips; (b) whiteflies and leafminers.

Gen. (Homoptera, Aleyrodidae)) were first seen on the sticky traps on 2 April 2001 (Fig. 2a, b). Starting with the second week, adults were observed even if the numbers were few. Nymphs of whiteflies started to appear after the tenth week (Fig. 2b). Due to the sticky yellow traps and applied preparations, the whitefly population remained below the economic threshold.

The damage due to leafminer (*Liriomyiza* sp. (Diptera, Agromyzidae)) was determined during the seedling stage, as intensive signs of ovipositing by females. NeemAzal T/S was applied on 16 April because of the high number of individuals on sticky yellow traps. After the third week, leafminer galleries were observed (17 April 2001) (Fig. 2b). The removal of the damaged leaves and neem treatment were effective, and, thus, leafminers were not seen once again after the seventh week (15 May 2001).

Thrips, *Frankliniella occidentalis* (Pergande), *Thrips tabaci* Lind. and *Aelothrip* sp. (Thysanoptera, Thripidae) were found during the second week and the highest intensity was at the eleventh week, as 3.98 individuals per leaf (Fig. 2a). Potassium soap applications against spidermites on 4, 12 and 18 June 2001 (Table 2) also affected thrips and killed most of the individuals.

The first spidermites (*Tetranychus cinnabarinus*) were present on the plants close to the entrance of the greenhouse, and sulfur was applied locally on 1 and 7 May 2001 in order to prevent their distribution (Table 2). However, the pest population increased after the twelfth week (18 June) and spread to all plants after the fourteenth week (Fig. 2a). Permitted preparations were applied weekly in April, May and June to control spidermites.

Aphids (*Aphis gossypii* Glover (Homoptera, Aphididiae)) were determined after the twelfth week, and the number of individuals was only 4.94 at the fifteenth week, due to precautions taken against spidermites (Fig. 2a).

Nematodes were not present in either soil samples or plant roots.

Cost analysis

Table 6 gives costs for construction of the greenhouses. Initial investment costs were determined to be US$6814 for

Table 6. Initial investment costs for greenhouse construction (384 m^2).

Item	Initial cost (US$)	%	Useful life (years)	Annual cost (US$)	%
Galvanized frame and kit	1821	26.7	20	91	14.8
Base locking rail	1565	23.0	20	78	12.7
Polyethylene (covering material)	264	3.9	2	132	21.5
Ground cover	54	0.8	2	27	4.4
Roof sprinkler (for frost protection)	198	2.9	20	10	1.6
Water pipe (PVC)	30	0.4	15	2	0.3
Water pipe (dropping)	103	1.5	10	10	1.6
Plastic filter	17	0.3	10	2	0.3
Metal filter	34	0.5	10	3	0.5
Nipple	10	0.2	10	1	0.2
Elbow (PVC)	15	0.2	15	1	0.2
Valve	40	0.6	15	3	0.5
Dilatation tank	62	0.9	15	4	0.6
Water pump	326	4.8	15	22	3.6
Site preparation and ground gravel	440	6.4	([1])	44	7.2
Assembly and installation	1835	26.9	([1])	184	30.0

[1] Calculated over 10 years.

Table 7. Net return obtained from each crop of organic greenhouse cucumbers as related to different organic fertilizer applications (US$ per 384 m^2).

Item	Organic fertilizer applications[1]			
	F_1	F_2	F_3	F_4
A. Variable costs	258	277	257	276
B. Fixed costs	409	409	409	409
Interest on total initial investment costs				
Semi-annual initial investment costs	307	307	307	307
Interest on total variable costs	15	17	15	17
Administrative costs	8	8	8	8
Land rent	29	29	29	29
Total	768	770	768	770
Total cost (A+B) (1)	1026	1047	1025	1046
Marketable yield (kg)	5196	5272	4988	4474
Average price of cucumbers (US$ kg^{-1})	0.33	0.33	0.33	0.33
Total gross return (US$) (2)	1715	1740	1646	1476

[1] Where F_1 = farmyard manure, 30 tons ha^{-1} + E 2001 + Allgrow Bioplasma; F_2 = farmyard manure, 50 tons ha^{-1}; F_3 = poultry manure, 30 tons ha^{-1} + E 2001 + Allgrow Bioplasma; and F_4 = poultry manure, 50 tons ha^{-1}.

384 m^2. In this regard, annual initial investment costs were calculated to be US$614.

Total variable production costs for each organic greenhouse cucumber crop varied between US$257 and US$277, according to different organic fertilizer applications. However, total costs of organic greenhouse cucumber production varied between US$1025 and US$1047 (Table 7).

The harvested organic greenhouse cucumbers were marketed at specific shops and supermarkets selling organic products, after being labeled and packed in plastic bags. Thirty percent of the cucumbers were sold for US$0.4 and the rest for US$0.3 per kg.

In this study, total gross revenue obtained from organic greenhouse cucumbers varied between US$1476 and US$1740 per crop, according to different organic fertilizer applications. Therefore, total net return (gross return minus costs) obtained with organic greenhouse cucumber production varied between US$430 and US$693 across all fertilizer treatments.

Discussion

Greenhouse yield varies widely according to variety, climatic conditions, growing season and related agricultural practices. In organic production, yield reduction is inevitable since the nutrient requirement of the crops are not minerally provided, due to the limitations imposed by international regulations. In fact, the nutrition might even be insufficient. Moreover, pest and disease damage is much more severe, since the use of protective synthetic chemicals is prohibited. Although an average crop yield reduction of 20% is accepted as normal[11], comparison of organic with conventional farming systems has indicated yield reductions of 11–24% for cabbage, 12–16% for radish, 6–7% for sweetcorn[12] and severe losses of up to 25–37% for carrot and cabbage[13]. Higher yield losses of 65–90% have also been stated for organically grown carrots, cabbages, onions, peas and potatoes[14]. In this regard, our previous studies on organic tomatoes indicated lower yield reductions[15]. All of these conflicting data indicate that pest and disease management is the key factor for a satisfactory yield. Naturally, the effect of other cultural techniques cannot be ignored.

In the study area, the cucumber plants in conventional farming systems generally yield 10–20 kg m^{-2} in short-term production, between March and mid-July or between mid-July and October–November. On the other hand, under unheated plastic greenhouse conditions in the same region, the yield can increase to up to 35 kg m^{-2} in long-term production (between March and October) (N. Aykut, personal communication). In this regard, the yield results (12.97 kg m^{-2}) of the present study are in agreement with local average yield data. As the practice of conventional farming in a greenhouse is not allowed next to an organic operation, the results of this study were compared with the results of a substrate culture that was operating near the same site, which revealed a yield reduction of 55% for organic cucumber production. Although this finding seems to be very high, the result can be considered reasonable when the low number of plants m^{-2}, the short-term production and the difficult pest management of the organic cultivation are taken into account. The reduced production costs and price premium for organic products are of further importance, since organic produce yielded a net return of US$1.12–1.79 per m^2; whereas the net return of the conventional bag culture produce[16] was only US$0.55 per m^2.

In the present study, irrigation treatments did not affect yield significantly. The amount of water used during the growing season differed by only 9%. The number of irrigations, and thus the irrigation frequencies, were different, and the long intervals between the irrigations were expected to create stress on the plants. However, the prevailing severe pest and disease damage was the primary stress and the cause of yield reduction. Even though no effect of irrigation was determined at the end of the study, if the

irrigation frequency is increased, as in a manually controlled greenhouse, the labor cost would also have increased.

In conventional greenhouse vegetable production, abundant amounts of plant nutrients are needed, which can not be used in organic production. In fact, plant nutrients from organic sources are limited, and it can be difficult to acquire the amounts needed (for instance, overmanuring of the soils can lead to N leaching). Therefore, plant nutrition cannot be controlled as precisely as in conventional production, and temporal quality problems can occur due to the imbalance in plant nutrition[17].

The disease incidence was low since the microclimatic conditions within the greenhouse, such as aeration, were unfavorable for fungal growth. Powdery mildew that developed during the growing periods could be controlled easily by removal of the leaves and the use of sulfur.

In cucumber production, pest problems appeared mainly on plants that were close to the entrance, thus signifying the need for effective sanitary measures.

The overall evaluation of the results proved that the management of pests and diseases in organic production of vegetables could be accomplished successfully using allowed preparations[18–20]. However, close monitoring and a quick response seem to be the key factors in achieving success. Biological control also has an important role in organic agriculture, particularly in greenhouses. Further studies may be required to optimize organic production as new solutions, changes or alternatives take place in the related regulations. The most important step in transition to organically grown greenhouse vegetables lies in the farmers' willingness to accept and get training.

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Substrates and fertilization for the rustic cultivation of *in vitro* propagated native orchids in Soconusco, Chiapas

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Abstract

Native orchid cultivation is a compatible alternative for impoverished coffee farmers in southeastern Mexico who are in crisis due to falling prices. Sustainable orchid cultivation is also an urgent necessity as an alternative to nonsustainable extraction from protected reserves, forest fragments and traditional coffee plantations, and to restore and conserve populations within these habitats. Our objective was to test the effects of locally available substrates and fertilizers upon orchids cultivated under typical rural conditions in coffee-producing areas in Soconusco, Chiapas. Seven species of epiphytic orchids native to Soconusco region—*Cattleya aurantiaca*, *Brassavola nodosa*, *Prosthechea* (*Encyclia*) *chacaoensis*, *Anathallis* (*Pleurothallis*) *racemiflora*, *Cattleya skinneri*, *Cycnoches ventricosum* and *Encyclia cordigera*—were propagated *in vitro*, acclimatized and established in rustic orchid galleries in the home gardens and plantations of coffee growers. Locally available waste products were used as substrates: clay tiles, tree bark, bamboo, seed hulls of pataxte (*Theobroma bicolor*) and wire baskets filled with bark chips. Two cheap and readily available commercial foliar feeds, Algaenzims (an organic product) and Bayfolan (a synthetic product) were tested. First, the substrates alone were tested for a period of 6 months to 1 year, then a combination of substrates and fertilizers were tested for 6 months, for effects upon leaf and root growth and root number. The mortality rates of these nonsymbiotically propagated, epiphytic orchids during the acclimatization phase, prior to these experiments, were high, between 60 and 90%. Once established in rustic galleries, the young orchid plants showed no preference for a particular substrate, survival depended upon technical problems during establishment, relating to difficulties with the attachment of plants to substrates, and the variable quality of care and attention offered by the farmers. Both fertilizers significantly improved one or all the parameters studied, and possibly counteracted the negative effects of the absence of symbiotic fungi, which, under natural conditions, are essential for orchid seed germination and adequate development of the young plant. More than half of the producers did not continue with the orchid cultures for economic and cultural reasons.

Key words: orchid cultivation, epiphyte, *in vitro* propagation, substrate, clay tiles, bark, bamboo, fertilization, acclimatization, conservation, coffee

Introduction

In this paper we present a general introduction to a relatively unknown sustainable option for coffee growers and, specifically, a study of the response of acclimatized, *in vitro* propagated plantlets of native, epiphytic orchids, to various locally available substrates and two brands of foliar fertilizer, within the context of the cultural conditions offered in the rustic galleries set up in the garden plots of coffee producers in six communities in the region of Soconusco, Chiapas. Epiphytic and terrestrial orchids are increasingly scarce in both natural and agro-ecosystems throughout the world, due to nonsustainable exploitation, and the deterioration, fragmentation or destruction of their habitats[1]. Epiphytic orchids are effectively mechanical parasites, they require other plants as supports but do not extract nourishment from their support plants. However, Benzing[2], cited by Koopowitz[3], suggested that under natural conditions they may be considered as nutritional pirates, competing with host trees for scarce and rapidly recycled nutrients. These plants require groups of mature trees, with trunks and branches covered in a rich flora of

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lichens, mosses, algae and fungi, which also implies the presence of a variety of cohabiting microorganisms, as well as insects, reptiles, amphibians and birds. That quality of substrate, found in tropical and temperate forests, takes several years to develop[4], during which epiphytes may be absent until the later stages of succession. Migenis and Ackerman[5] studied 11 species of orchids in a subtropical humid forest in Puerto Rico and emphasized the importance of the size (i.e., age) of the tree as a determinant factor for orchid presence. To recover a deteriorated forest may take several decades, and epiphytes may never recolonize the trees if there are no nearby sources of seeds and mycorrhizal fungi to facilitate the germination of those seeds[6,7]. Orchids may be more frequent on certain tree species, as discussed by Benzing[2], but are usually not specific[8]. Preferences for substrates may relate more to the prevalent ecological conditions[9] and the distribution and preferences of the mycorrhizal fungi, than to the nature of the support itself.

Mexico is one of the biodiversity hotspots in the world, within which Chiapas is the second most biodiverse state, with neighboring Oaxaca at the head of the list. More than a thousand species of epiphytes have been described in the country as a whole, and many of these are currently designated as in danger of extinction and live precariously in forest fragments, coffee plantations and solitary, often senile trees in pastures.

The region of Soconusco in the state of Chiapas in southeastern Mexico comprises the coastal lowlands and Pacific slopes of the Sierra Madre mountains that line the west coast of Mexico. It is a region renowned for its rich alluvial soils and agricultural production, but which is now suffering from a population explosion, immigration and emigration, contamination and advanced deforestation, as well as complicated political, social and economic problems. Agricultural production in Mexico in general is suffering competitive pressure from all sides, and coffee, one of the main agricultural products, has been particularly severely affected. Both Arabica (*Coffea arabica* L.) and Robusta (*C. canephora* Pierre ex Froehner) coffees are grown, on the higher and lower slopes of the Sierra Madre, respectively. Coffee can be grown using various systems, from the extremes of high-technology, high-input, shadeless coffee, to rustic, organic/biodynamic/ecological systems under shade trees, and with different certification requirements which may include such aspects as terracing on slopes, the provision of food sources for migratory birds, environmental education for the children of plantation laborers and the maintenance of shade tree diversity. The ideal altitude range for coffee-growing is 600–1500 m and this coincides roughly with the zone of maximum diversity of vascular epiphytes in the region, which was confirmed by Wolf[10] as 500–2000 m.

Within this scenario, therefore, coffee plantations are important for people and for many other organisms, but diversification of production is an urgent necessity for the economic and social well-being of producers. In the long term, the cultivation of native orchids could be a compatible, viable option for coffee producers, and the certified product can be sold in various forms (e.g., cards, invitations and wall-hangings with pressed flowers; conserved, three-dimensional flowers in presentation boxes; whole plants with flowers on a variety of supports; flasked *in vitro* plantlets where money is available for investment in equipment) and also used to repopulate plantations and depleted forests. Orchids can be collected from the ground, fallen branches, felled and rotten trees, or they can be propagated *in vitro*, by seed[11]. The use of tissue culture methods is not recommended here, not only because genetic diversity and plasticity are sacrificed[3], but also because of the costs involved. All species of orchids are protected internationally by CITES and within Mexico by the NOM-059-ECOL-2001[12], a situation that has been shown to be both corruptible and to deter many positive contributions to the conservation of these plants[3]. Furthermore, laws referring to the conservation of flora and fauna are barely recognized in most parts of the developing world, and few are willing to pay a suitably high price, that would reflect the scarcity and importance of the product and the challenges that represent attempts to cultivate it successfully. One of the most difficult aspects of this type of project is the awakening of interest in a product derived from protected species, which is usually followed by a surge of illegal collection and copycat, but uncertified, products offered at much lower prices.

As part of a multidisciplinary group effort set up by ECOSUR[13] to ameliorate the social, economic and environmental crisis in the coffee-growing areas of the southeast of Mexico, a pilot project for the rustic and sustainable production of orchids has been set up. One of the aims of this group is to offer alternatives so that impoverished coffee growers feel less inclined to erase or transform shaded coffee plantations, which effectively replace lost tropical forests and are vital as habitats for the persistence of many species of flora and fauna. The orchid project includes training, long-term assessment and plans for the certification of the product, both as an example to follow, and also to ensure that the product sells at an appropriate price. It is important to take into consideration the slow rate of growth and maturation for most species of orchids, which may take several years to produce their first flowers. There is virtually no literature concerning rustic, sustainable orchid cultivation, other than guides for amateur growers in developed countries, which would be inapplicable in rural Soconusco. Also, surprisingly, there is very little practical information concerning highly technical, commercial methods (*in vitro*, tissue culture, etc.), which often remain as 'in house' secrets of the major orchid-growing companies.

It would be considered logical to plant the orchids onto shade trees within the coffee plantations and harvest viable sections by division (vegetative propagation) at determined intervals; however, this is not possible, due to theft and competition between growers. In this program, the orchids

Figure 1. Orchid gallery constructed with wooden poles and 'manaca' palm leaves. The orchids, attached to substrates, hang from the wires that support the palm-leaf roof.

are grown in rustic structures called 'galleries' (Fig. 1), measuring from 4×4 m to 10×10 m, which are constructed within visible distance of the house, effectively forming part of the home garden or 'transpatio'. Posts can be made from wood but, for ecological reasons, concrete is preferable. Shade can be provided preferably by live trees or palm (usually 'manaca', *Scheelea preussii* Burret) leaves, but shade cloth can be employed where necessary.

Arboreal habitats and the epiphytes that inhabit them are complex and poorly understood. These habitats are usually considered as nutrient poor[14,15], giving rise to the need for obligate and facultative symbiotic interactions between coexisting organisms and epiphytes. In contrast, however, the analysis of the content of arboreal 'soils' (accumulated detritus, organic matter, canopy mats, etc.) in Costa Rican forests by Lesica and Antibus[16] revealed relatively high nutrient levels, and the latter authors mentioned other studies with similar results. Epiphytic orchids in all but the most humid environments feed in a dynamic and highly competitive environment for short periods only, during rainfall, and typically absorb nutrients dissolved in rainwater rapidly and efficiently, via both roots and leaves[17]. Orchids are also characterized by their ability to store water and nutrients in fleshy pseudobulbs and/or leaves, indicating permanent or temporal scarcity. Regular, low-dosage foliar fertilization can, therefore, be considered an appropriate method for the rustic cultivation of native orchids. Substrates for orchids can be natural, which may include nonrenewable resources such as tree-fern fiber (however, bear in mind the protected status of some species of tree ferns) and waste products, such as coconut fiber, which retain sufficient water[18], or artificial substances, which are often expensive and difficult to obtain. In cultures where orchid cultivation is a centuries-old tradition, materials used as fertilizer are diverse and often highly creative and idiosyncratic; Hew[19], reviewing ancient Chinese practices, mentions the use of goat and goose manure, and water in which fishes have been washed, as fertilizer.

Materials and Methods

The project began with the testing of four culture media for the propagation by seed, *in vitro*, of seven native species of orchids:

1. First phase (2000–1): *Cattleya aurantiaca* (Bateman ex Lindley) P.N. Don; *Brassavola nodosa* (L.) Lindley; *Prosthechea* (*Encyclia*) *chacaoensis* (Reichb.f. Dressler & Pollard). W.E. Higgins.
2. Second phase (2001–2): *Anathallis* (*Pleurothallis*) *racemiflora* (Sw.) Pridgeon & M.W. Chase; *Cattleya skinneri* Bateman; *Cycnoches ventricosum* Bateman; *Encyclia cordigera* Kunth Dressler.

The *in vitro* propagation was carried out as a service provided by the 'Centro Internacional de Investigación y Capacitación Agropecuario' (CIICA) in Ciudad Hidalgo in Chiapas, Mexico. The response of the seeds and plantlets of these orchids to the different culture media used was varied and protocols were established for *B. nodosa* and *C. aurantiaca*[20]. Plantlets were acclimatized for a period of 6 weeks in protected units in CIICA before being passed to the Regional Botanical Garden 'El Soconusco' in the municipality of Tuzantán, Chiapas, for further adaptation to field conditions. The process of acclimatization caused high mortality rates for all species, between 60 and 90%. The time from seed germination to the delivery of the surviving plants to the orchid galleries varied from 1 year to 18 months.

The acclimatized plantlets of the seven species of *in vitro* propagated orchids were delivered to the orchid galleries in rural coffee-producing communities in Soconusco, and fixed onto, or planted into, five substrates: bark, wire baskets filled with bark chips, clay tiles, bamboo and hulls of pataxte seeds, *Theobroma bicolor* Bonpl (a relative of cocoa, *T. cacao* L.). All plants, once attached to their substrates, were suspended by sections of cable from the wires that effectively form the 'roof' of the rustic galleries, at a height of approximately 1.80 m above the ground (Fig. 1). Plants were left to settle down for a month before data were taken, and mortality during this period was not taken into account. At first, responses to the different substrates alone were compared during a period of 6 or 12 months (second phase and first phase, respectively). This was followed by a comparison of the responses to two foliar fertilizers, 'Algaenzims' (BASF, New Jersey, USA) and 'Bayfolan' (Bayer Mexico, Mexico City) in combination with the different substrates, during a period of 6 months.

The materials chosen as substrates were all locally available and natural substances, except for the wire used for the baskets; and some could be considered as waste products, such as: clay roofing tiles, pataxte hulls, bamboo, bark and the bark chips used to fill the wire baskets. Bark from 'cedro' (*Cedrela odorata* L.: *Meliaceae*), 'roble' (*Tabebuia rosea* (Bertol.) A. DC.: *Bignoniaceae*) and 'primavera' (*Cybistax donnell-smithii (Rose) Seib.: Bignoniaceae*) were used and cut to various sizes (30×20 cm to

50 × 30 cm), depending upon the size of the orchid plants. Small plants without pseudobulbs were attached by small patches of superglue, and larger plants were tied on using 50-caliber nylon fishing line. Substrates were selected according to availability and producer choice, for that reason there were insufficient replicates to permit statistical analysis of the data for some of the substrates. The fertilizers selected were chosen because of their price, availability and the fact that they represent different types and formulations of fertilizer.

Algaenzims (BASF) is an organic product, with 4% of the organic matter comprising seaweed. It contains a wide range of minerals and trace elements which may be limiting factors in epiphytic habitats, and small quantities of plant hormones (cytokinins and gibberellins) which variously affect growth and root, bud and shoot development, depending upon concentration, the timing of application and combinations with other hormones[21].

Bayfolan (Bayer) is a synthetic product which, according to product information, comprises: 11% N (derived from ammonium nitrate, potassium nitrate, biammonium phosphate and ammonium sulfate), 8% P_2O_5 (biammonium sulfate and phosphoric acid) and 6% K_2O (potassium chloride, potassium nitrate and potassium sulfate). The vitamin B_1 content favors root growth, nutrient assimilation and respiration, whereas the presence of auxins (indoleacetic acid) promotes cell extension, tissue differentiation, respiration and shoot development. The product also contains chelated micro- and macroelements and a wetting agent.

In these experiments the results from the different galleries were pooled and, for the purpose of analysis, were considered as a single site, representative of the environmental conditions present in the coffee-growing areas of Soconusco. The process of the setting up of the orchid cultures and the subsequent care of the plants were standardized; all producers received the same training.

Reaction to substrate

Fifteen producers participated in this first stage of experimentation, comprising a total of 2963 plants (Table 1). After the plantlets were placed onto or into their substrates and suspended from the roof of the rustic galleries, monthly evaluations were carried out, which included discussions with the producers about any problems they might be experiencing, the amount of shade, incidence of pests and diseases, and the water requirements of the plants. Data were taken of the number of healthy, sickly and dead plants, for each orchid species within each substrate category, during a period of 12 months (first phase) or 6 months (second phase). At the end of the experimental

Table 1. Percentage survival of acclimatized plantlets, at 18 months (first phase) and 1 year (second phase), of orchids propagated *in vitro* by seed and placed in rustic galleries in the home gardens of coffee producers, in Soconusco, Chiapas. Percentages emphasized in bold and those underlined are the species with the highest survival rates, and the preferred substrates for each species, respectively.

Orchid species (total % survival)	Original number of plants	Substrate				
		Bark	Clay tiles	Bamboo	Wire basket and bark chips	Pataxte (small sample size)
First phase (at 18 months)		--------Percentage survival ± standard deviation across galleries-------- --------(number of galleries, total number of plants in trial)--------				
Cattleya aurantiaca (**67%**)	905	65 ± 29% (14, 314)	64 ± 26% (14, 289)	70 ± 12% (9, 169)	65 ± 30% (14, 122)	82 ± 17% (3, 11)
Brassavola nodosa (**67%**)	991	67 ± 31% (14, 991)	63 ± 22% (13, 284)	61 ± 27% (10, 217)	61 ± 32% (14, 133)	67 ± 30% (3, 12)
Prosthechea (*Encyclia*) *chacaoensis* (45.08%) (small sample size)	122	52 ± 40% (13, 46)	44 ± 43% (12, 55)	10 ± 23% (8, 21)	30 ± 28% (6, 10)	29 ± 29% (3, 7)
Second phase (at 1 year)						
Encyclia cordigera (**79%**)	360	79 ± 18% (7, 132)	80 ± 20% (7, 64)	78 ± 25% (7, 91)	80 ± 29% (5, 39)	86 ± 23% (1, 4)
Anathallis (*Pleurothallis*) *racemiflora* (41%)	248	43 ± 19% (7, 104)	64 ± 36% (6, 47)	29 ± 14% (7, 68)	–	24 ± 18% (4, 29)
Cattleya skinneri (56%)	216	65 ± 24% (7, 66)	29 ± 23% (5, 38)	62 ± 33% (6, 60)	75 ± 23.1% (4, 16)	39 ± 45% (5, 31)
Cycnoches ventricosum (11.57%) (small sample size)	121	19 ± 30% (7, 54)	41 ± 22% (5, 19)	3 ± 6% (5, 29)	40 ± 12% (2, 5)	0 ± 0% (3, 13)

Table 2. Distribution of orchid species and substrates.

Orchid species	Total number of plants	Substrate			
		Bark	Clay tiles	Bamboo	Wire basket and bark chips
Brassavola nodosa	279	144	101	17	17
Cattleya aurantiaca	215	94	88	15	18
Cattleya skinneri	18	18	–	–	–
Encyclia cordigera	103	56	15	15	17
Prosthechea (E.) chacaoensis	47	18	29	–	–

period, data were pooled and percentage survival of each species of orchid was calculated for each substrate.

During and at the end of the first phase, the producers who did not dedicate sufficient time and attention to their plants were eliminated from the project, and the second phase was carried out with the participation of the six most committed producers. The surviving plants from phase 1 were used for the trials in phase 2, but there were too few plants of *C. ventricosum* and *A. (P.) racemiflora* for inclusion in the second phase.

Reaction to fertilizer plus substrate

Six producers participated in this second stage of experimentation, all having proved to be interested in the project and consistent in their care of the young orchid plants. The substrate pataxte was not included at this stage due to insufficient material. A total of 662 plants were included in these trials (Table 2).

In each of the six rustic orchid galleries, for each orchid species and each substrate, the number of healthy plants available was divided equally and randomly among the three treatments: control; Algaenzims at half dose (as indicated for ornamental plants in the instruction leaflet); and Bayfolan, similarly at half dose. The plants were labeled with different colored tags, according to treatment, and were sprayed with one of the fertilizers or with chlorine-free, clean water, every 15 days during the growing (rainy) season for a period of 6 months, from April to October 2003. According to designation, the fertilizers or chlorine-free water were applied evenly to the plants by technical staff of the project, using the same sprayer for each treatment, or control, throughout.

At the beginning of the experiment, for each plant selected for inclusion in the study, measurements were taken of the length of the largest leaf and length of the longest root and the total number of roots. Measurements were repeated at 3 months and at the end of the 6-month experimental period.

Using three parameters chosen to define development (growth of longest leaf, number of roots, growth of longest root), comparisons were made between the development of the young orchid plants using four substrates (bark, clay tiles, wire basket, bamboo) and three treatments (control, Algaenzims, Bayfolan).

For statistical analysis, differences were calculated between the initial measurements and the measurements at 3 months (T1) and between the initial measurements and those at 6 months (T2). Data taken from the six galleries were pooled and analyzed using STATISTICA 6 (StatSoft, Tulsa, Oklahoma, USA) software. A univariate repeated measures analysis of variance (ANOVA) was applied and orthogonal contrasts were used to compare means.

Results

Reaction to substrate

The numbers of plants surviving to the end of the first phase was very variable, and related more to the quality of care offered by the producers than to the substrate. Furthermore, each producer used materials that were available to him, and the quality of such materials, such as bark and bamboo, was also variable. Data from this first phase were not suitable for statistical analysis, but percentage survival of the plantlets, in relation to each substrate, was calculated as a rough guide (Table 1). Survival was very similar for most substrates for both *E. cordigera* and *B. nodosa*.

More than half of the producers were eliminated from the project due to inadequate care of their plants. Once the plants were installed, many producers were unable to visualize the long-term benefit of caring for very small plants that grew very slowly and would flower in 4–6 years. During introductory talks, the realities of orchid cultivation and the importance of long-term and sustainable cultivation strategies were explained and discussed at great length prior to the installation of the crop, whereupon most producers declined to enter the project. Despite further training and long-term follow-up and assessment, a proportion of those who did commit themselves did not absorb the information and still hoped for a miracle crop that would solve their economic problems in a minimum of 6 months. Furthermore, displaced populations with no historical ties to their current plots, lack of general education, poor role models, environmental deterioration, lack of governmental commitment, corruption and mass emigration to the Unites States make it very difficult for new and long-term visions to be adopted by rural campesinos; they do not believe in themselves, their land or their government, and are more accustomed to

Table 3. Leaf and root growth of *Brassalova nodosa*, at time 1 (T1) and time 2 (T2), as influenced by substrate type and fertilizer treatment.

	Substrate					
	Clay				Bark	
	Leaf growth (cm)		Root growth (cm)		Leaf growth (cm)	
Treatment	T1	T2	T1	T2	T1	T2
Control	0.35a	0.74a	0.31a	0.60a	0.41a	0.84a
Algaenzims	0.56b	1.28b	0.52b	1.04b	0.63b	1.25b
Bayfolan	0.67b	1.31b	0.56b	1.17b	0.67b	1.28b

Significant differences (at $P = 0.05$) within a column are indicated by different letters.

short-term handouts than to well-planned, hard work. Within that context we consider it a victory to have maintained these producers within the project for several years (some are now in their fourth year).

Reaction to fertilizer plus substrate

For various reasons, as explained in the discussion, survival was poor and there were insufficient data for statistical analysis for *A.* (*P.*) *racemiflora* and *C. ventricosum*, and very few data for *P.* (*E.*) *chacaoensis*. Statistical analysis could not be carried out for number of roots, due to the large number of zeros in the data; roots proved to be attractive to foraging small birds, insects and reptiles, especially basilisks (*Basiliscus* sp. Squamata: Corytophanidae).

Statistical analysis was carried out for bark and clay tiles for the three orchid species that showed highest survival rates. Some plants were lost and the numbers of plants that survived to the end were fewer than those presented in Table 2. There were no cases of a significant difference between the two fertilizers.

Brassavola nodosa. Plants on clay tiles showed significantly better leaf and root growth with both fertilizers, as compared to the control, and plants on bark showed significantly better leaf growth with both fertilizers (Table 3).

Cattleya aurantiaca. Plants on clay tiles showed significantly better leaf growth with both fertilizers, as compared to the control, and plants on bark showed significant improvements in leaf and root growth (Table 4).

Encyclia cordigera. For plants planted onto bark, Algaenzims and Bayfolan promoted significantly better leaf growth as compared to the control (Table 5).

Where statistical analysis was not carried out due to low numbers of repetitions, numerical advantages were observed in most cases for one or both fertilizers, as compared to the control, and were particularly notable for the following: bamboo, *E. cordigera*, leaf growth with Algaenzims; wire basket with bark chips, *E. cordigera*, leaf growth with Algaenzims; bark, *C. skinneri*, number of roots with both fertilizers; clay tiles, *P.* (*E.*) *chacaoensis*, leaf and root growth, with both fertilizers.

P. (*E.*) *chacaoensis* gave a poor response to all the substrates offered and was susceptible to infection by the fungus *Myrothcium* sp. (identified by Carlos Garibay-Gálvez, CIICA, 2001) at all stages of the study, from *in vitro* germination of seeds, through acclimatization, to growth and development in the rustic galleries, despite being the most common, widely distributed, resistant and weedy species of orchid found in Soconusco region.

A. (*P.*) *racemiflora* responded relatively well at all stages, and most losses were due to the technical problems

Table 4. Leaf and root growth of *Cattleya aurantiaca*, at time 1 (T1) and time 2 (T2), as influenced by substrate type and fertilizer treatment.

	Substrate					
	Clay		Bark			
	Leaf growth (cm)		Leaf growth (cm)		Root growth (cm)	
Treatment	T1	T2	T1	T2	T1	T2
Control	0.40a	0.88a	0.41a	0.81a	0.37a	0.70a
Algaenzims	0.61b	1.11b	0.66b	1.24b	0.49b	0.95b
Bayfolan	0.73b	1.38b	0.63b	1.24b	0.63b	1.21b

Significant differences (at $P = 0.05$) within a column are indicated by different letters.

Table 5. Leaf growth of *Encyclia cordigera* at time 1 (T1) and time 2 (T2), as influenced by substrate type and fertilizer treatment.

	Substrate	
	Bark	
	Leaf growth (cm)	
Treatment	**T1**	**T2**
Control	0.32a	0.76a
Algaenzims	0.62b	1.22b
Bayfolan	0.49b	1.11b

Significant differences (at $P = 0.05$) within a column are indicated by different letters.

associated with fixing the plantlets onto their substrates; this species lacks pseudobulbs and the plantlets were too small to be tied onto the substrates. After elimination of other methods for various reasons, a brand of 'superglue' was used which proved nondamaging to the plants. The technique functioned best with clay tiles; however, many of the plants became unstuck and fell to the ground, where they disappeared from sight. This small plant did not adapt well, at this stage, to a horizontal existence in the wire baskets, but larger plants have been transplanted successfully into baskets.

C. skinneri was delicate at all stages of production and, like *P.* (*E.*) *chacaoensis*, was susceptible to fungal infections. The response of this showy species was similar for wire baskets, bark and bamboo, but mortality was higher for clay tiles and pataxte.

C. ventricosum is a beautiful, deciduous orchid which remains leafless throughout the 6 month dry season that is typical of the Soconusco region. The *in vitro* propagation of this species was difficult and presented various novelties. At one stage the plants shed their leaves and the pseudobulbs suddenly turned a dark brown color and were about to be thrown out, when a flush of new leaves was produced throughout the culture. The plantlets produced round pseudobulbs early on in their development and lost and replaced their leaves every 2 or 3 months, which was probably an exaggerated deciduous response to the cultural conditions, as compared with wild, mature plants which drop their leaves once, at the beginning of the dry season, to be replaced 6 months later at the onset of the rains. The plants of this species were also difficult to fix to the substrates and many were lost due to problems with the glue, as for *A.* (*P.*) *racemiflora*.

By comparing the controls, the results suggest that bark offers better conditions than clay tiles for *B. nodosa*, but that bark and clay tiles offer very similar conditions for *C. aurantiaca*. It is interesting to note that the fertilizers promoted significantly better leaf and root growth for most plants on clay tiles but only improved leaf growth for plants of *C. aurantiaca* on bark, suggesting that bark supplies sufficient nutrients for root growth, but not for leaves.

Discussion

In the first phase of this study, the nature of the substrate itself had little effect upon the survival rate of plantlets of the most robust orchids, *E. cordigera*, *B. nodosa* and *C. aurantiaca*, in that order. In the second phase, reactions between substrates and orchid species were variable; there was, however, a clear trend that both fertilizers improved the development of the orchids in at least one of the parameters studied.

Orchid plantlets produced asymbiotically *in vitro* are notoriously difficult to adapt to natural conditions; the epidermis of plants contained within the sealed, sterile flasks is very thin and plants are thus vulnerable to pests and pathogens and dehydrate very quickly. The plants require slow, progressive changes in order to acclimatize to fluctuations of humidity and temperature and invasion by bacteria and fungi[22]. For all seven species of orchids in this study, the numbers of surviving plants 3 years after germination *in vitro* was extremely low, which can be attributed to the variable quality of attention given to the plants by the farmers and the lack of a suitable mycorrhizal fungal inoculant, which under natural conditions facilitates the nutrition and thus fortifies young plants; in these experiments the plants were all of unselected, wild origin.

Under natural conditions, orchids feed upon sources of N, P and K dissolved in rainwater and organic matter trapped between forked branches, and in fissures and rough surfaces of tree bark, as well as amongst the roots, leaves and stems of climbers and epiphytes. Rainwater is obviously varied in its composition, but, as a reference, the analysis done by Ospina[23], in the Central Amazon, indicated that water containing 2.11 $mg\,l^{-1}$ Na, 0.1 $mg\,l^{-1}$ K, 0.07 $mg\,l^{-1}$ Ca, 0.02 $mg\,l^{-1}$ Mg and 0.095 $mg\,l^{-1}$ P was the main nutrient source of orchids. However, the study did not include analysis of leachates from leaf litter and direct deposition of invertebrate (and sometimes vertebrate) carcasses and excrement.

The requirement for fertilizers depends upon the nature of the substrate. According to Arditti[17], most organic materials that undergo moderate degradation do not require fertilizer, but tree bark has been shown to be an exception and additional fertilization is recommended. The ability of bark to retain water varies according to age[3] and species.

The benefit gained by the application of fertilizers reflects, in part, the capacity of the substrate to saturate the requirement for minerals and N, P, K of the young orchid plants. Bark is mentioned in the literature as a nutrient-deficient substrate, and numerical or significant improvements were observed with both fertilizers in most cases, but mainly for leaf growth, the growth of the longest root was not much improved. The quality of bark was very variable between the different galleries, with variation due to different species of tree, different ages of the living tree

(which is reflected by the microflora present) and the state of decomposition of the bark. Wire baskets filled with pieces of bark also showed a general improvement with both fertilizers, for all three parameters, but to a lesser degree. In this case, the accumulation of organic detritus due to the activities of ants and numerous other insects cohabiting between the layers of bark probably contribute to orchid nutrition. Wire baskets are not, however, advisable in very humid and shady environments, due to the accumulation of excessive humidity which causes rotting of the plants, worsened if the farmer insists on watering regularly without checking the prior condition of the plant and substrate. Clay, being compressed, baked earth, should be a source of various minerals and N, P and K; however, in drier and sunnier areas this substrate requires more frequent watering and, without moisture, the mineral content becomes inaccessible. This substrate was shown to be equal, or very slightly inferior, to bark as a substrate in this study, probably due to lack of watering. Bamboo benefited from the application of both fertilizers, and Algaenzims was especially efficient at promoting leaf growth for this substrate. Neither fertilizer showed clear superiority for promoting leaf or root extension in any of the substrates.

Conclusions

This century, product diversification on a wide scale will be essential to combat poverty, market domination and environmental degradation. The production of native orchids is a promising alternative for coffee farmers in the Soconusco region and may be combined with ecological and organic coffee, ecotourism and the elaboration of arts and crafts. Similarly, epiphytic bromeliads are another alternative, and Wolf[24] suggests methods for evaluating populations and determining sustainable extraction quotas.

Many campesinos in the Soconusco region of Chiapas are reluctant to commit themselves to programs promoting diversification, secondary economic activities and new solutions to old economic problems, and even less so if these programs imply waiting for long-term results. Such programs are tainted with a history of failure, and most options are presented to producers via poorly planned and corrupt programs linked to ephemeral political interests. In short, producers lack good role models; they have no evidence that new techniques, dedication and attention to detail reap benefits. Many of the producers involved in this program participated only half-heartedly and were incapable or unwilling to learn and apply the techniques offered. None the less, a proportion of the coffee farmers who joined this program for the rustic and sustainable cultivation of orchids achieved positive results, which could be traced back to an enthusiasm for learning and mastering a new crop, attention to detail, regular revisions of the young plants and personal initiative when rapid solutions were necessary for unforeseen problems. We feel that key points for the success of this type of project are an adequate selection process prior to commitment to the project and frequent and long-term assessment.

Orchids grow very slowly, and the plants in this study, at 3 and 4 years old, were still very small. The significant gains in length of leaves or roots, or the number of roots, although perhaps not fully appreciated by the orchid growers, were nevertheless highly significant for both plant and grower. Pests and diseases were not a significant problem, but one pest, a mirid bug[25], when it occasionally appeared, required very prompt action to avoid damage.

A range of organic waste products can be used for rustic orchid cultivation without affecting the establishment and development of the orchid plants, provided that basic requirements for water and shade are met. Low-dosage foliar fertilization is an appropriate method for the rustic cultivation of native orchids. Algaenzims and Bayfolan, applied at half dose, in combination with clay tiles, bark, wire baskets filled with bark chips and bamboo substrates significantly increased leaf growth and/or root growth of acclimatized, 3- and 4-year-old plants of five orchid species propagated *in vitro* and established in rustic galleries in rural communities in the Soconusco region.

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An integrated approach to crop/livestock systems: Forage and grain production for swath grazing

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Abstract

Current agricultural systems are the result of decoupling crop/livestock enterprises for short-term economic gain at the expense of long-term sustainability. Objectives of our research were to determine the influences of winter grazing dry gestating beef cows on no-till forage and grain production, water-use efficiency, and protein and phosphorus (P) production for an oat/pea–triticale/sweet clover–corn 3-year cropping system. Oat/pea and triticale crops were harvested for grain, with the straw and chaff left in swaths after harvest for winter grazing. Drilled corn for forage was swathed in late September. Cropping system treatments were: (1) straw and corn chopped and left in place (IP); (2) straw and corn baled and removed without livestock (R); and (3) straw and corn swath grazed by livestock (L). The first winter for grazing dry, bred cows was in 1999–2000; therefore, no treatment differences occurred for the 1999 crop. In 2000, oat/pea and triticale grain and straw production for the IP treatment was about half of the production for the R treatment, because of low oat/pea and triticale plant stands on the IP treatment. Averaged over all years, corn was about 1.5 times more efficient in using water for dry matter production when compared to oat/pea or triticale. Generally, protein and P production, on a unit area basis, were highest for corn and lowest for triticale. Averaged over 4 years, about half of the nitrogen used for protein production was derived from sources other than applied commercial fertilizer. Data suggest that more than 4 years of research are needed to understand cropping system and animal interactions on forage and grain production in integrated crop/livestock systems, with trends in year four suggesting that livestock may enhance forage and grain production.

Key words: no-till, corn, triticale, oat/pea

Introduction

Agriculture has evolved over the decades from simple cultivation to a number of differentiated forms. As individual farms have become more specialized, separate crop and livestock systems have evolved and it has become more difficult and costly to recycle waste[1]. Specialization has resulted in uncoupling of crop and livestock production enterprises, to focus in on one or two crops or livestock alone. Chemicals to control pests in crops have made management simpler in the short term but, invariably, chemicals can create long-term problems for the future[2,3]. Diversity provides the key to overcoming problems and can help to ensure productive and profitable agriculture for the future. Agricultural stability that arises from adding diversity to the system can be attained by including multiple annual and perennial crops in a system, intercropping multiple crops and, probably the most important, integrating crops and livestock into a system[3,4]. Biological sustainability is the length of time a particular system can be maintained; we have often used chemicals as a substitute for crop diversity in predominately monoculture systems to try to make these systems biologically sustainable[1,4].

As technology has become more sophisticated, researchers and extension workers have become more specialized and have tended to develop their own vocabulary to facilitate communications among themselves[5]. This narrowing of research focus, away from whole-farm systems and towards its components, has resulted in researchers who are less able to communicate with producers because

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producers do not understand the specialized vocabulary. To overcome this narrowing of focus, which has resulted in information of little importance to producers, we need to develop multidisciplinary teams that work collaboratively on whole-farm systems[5]. Multidisciplinary efforts often fail because teams are organized as committees, that meet occasionally, rather than as a functioning cohesive working group. By addressing problems as a working group, individuals representing each area of research specialization understand each component of the whole-farm system. Development of this cohesive working group helps to ensure that relevant problems are researched and appropriate criteria are used in the interpretation of data. This multidisciplinary working group requires significantly greater time to participate in research planning, decision making and synthesis of research data[6].

One of the most difficult whole-farm systems to work with, for researchers who are specialized, is the crop/livestock system[6]. Adding livestock to a cropping system complements both crops and livestock by adding value to the grain, allowing for efficient nutrient cycling and providing a use for forages, small grains and crop residues[3,7]. Livestock also provide an opportunity to add species diversity to the cropping system and to take advantage of synergism and niche complementarity effects among plant species for greater productivity than monoculture systems[8].

Since 1978, Canadian researchers and producers have evaluated cropping systems that include small grain crops such as oats, barley, fall rye and winter triticale for winter swath grazing[9,10]. Cattle can swath graze through as much as 50 cm of snow[11], but for a variety of reasons, swath grazing has had minimal use in the US. Most of the Canadian swath grazing has involved livestock only, with little or no thought to livestock influences on crop production or soil properties. The broad-scope objective of our research was to establish a cohesive working group of scientists to develop a crop/livestock integrated system that would provide feed to meet the nutritional requirements of dry bred cows during the winter and provide adequate crop diversity in time and space for sustainable crop production. The specific objective of this paper was to determine the influence of feeding dry gestating cows on no-till forage and grain production, water-use efficiency, protein production, and forage phosphorus (P) production for a 3-year cropping system in the northern Great Plains.

Materials and Methods

Research was conducted 5.0 km southwest of the Northern Great Plains Research Laboratory in Mandan, North Dakota. Soils at the site were characterized by gently rolling uplands (0–3% slope) with a silty loess mantle overlying glacial till. Soils at the site were classified as a Wilton silt loam (fine-silty, mixed superactive frigid Pachic Haplustolls). Soils at the site had an average nitrate nitrogen (NO_3-N) level of 14.6 kg ha^{-1} in the surface 60 cm of soil and an extractable sodium bicarbonate P level of 4.0 mg kg^{-1} in the surface 30 cm of soil. Two 6.0 ha pastures that had been in crested wheatgrass (*Agropyron desertorum* Schult.) for at least 15 years were chosen to initiate a 3-year cropping system. Crops in the system were oat/pea (*Avena sativa* L./*Pisum sativum* L.) in year 1, triticale/sweet clover (*Triticum aestivum* × *Secale cereale*/*Melilotus officinalis* L.) in year 2, and corn (*Zea mays* L.) in year 3. Crops were arranged to provide an integrated crop/livestock swath grazing systems approach (Fig. 1). Any crop regrowth or volunteer crop was left to grow, as well as any sweet clover, and used for winter grazing or soil cover. Quantity of regrowth was minimal. Oat/pea straw was swath grazed first, followed by triticale/sweet clover straw, then swathed corn. Because of dry conditions in 2002, oat/pea and triticale/sweet clover were swathed when oat and triticale were at anthesis, and baled. Bales were fed at the same time and order as the swathed straw.

The experimental design was a randomized complete block for pastures with unbalanced treatment replications. All phases of the cropping system were present each year. Treatments were residue or stover left in place with no livestock (IP), residue or stover removed with no livestock (R), and residue or stover grazed by livestock (L), dry bred cows. The IP and R treatments had two replications, while the L treatment had 12 pseudo-replications. The L treatment for each pasture was divided into six grids to estimate variables of grain and straw production and forage production. A mixed model[12] approach was used to determine least squares means for treatments and to determine statistical differences at the 0.10 probability level.

In 1999, the two crested wheatgrass pastures were sprayed with glyphosate [*N*- (phosphonomethyl) glycine] at 0.7 kg a.i. ha^{-1} in mid-May, followed by a second application at the same rate 6 days later. For corn, an additional application of glyphosate at 0.34 kg a.i. ha^{-1} plus dicamba (3,6-dicloro-2-methoxybenzoic acid) at 0.13 kg a.i. ha^{-1} was made in early June prior to planting. In subsequent years, glyphosate at 0.84 kg a.i. ha^{-1} plus 2,4-D (2,4-dichlorophenoxyacetic acid) at 0.84 kg a.i. ha^{-1} were applied to oat/pea and triticale/sweet clover plots prior to seeding. For the corn plots, glyphosate plus 2,4-D, at the same rates as used for oat/pea and triticale/sweet clover plots, were applied in early June prior to planting. No post-emergence herbicides were used for in-crop weed control, which reduced the quantity of pesticides used when compared to traditional no-till crop production.

In mid to late May, 1.74 million viable seed ha^{-1} of oats and 0.74 million viable seed ha^{-1} of pea were mixed and seeded together. Triticale at 2.5 million viable seed ha^{-1} and 11 kg ha^{-1} of sweet clover were seeded during the same time period. In early June, corn was drilled at 197,000 viable seeds ha^{-1}. All crops were seeded with a John Deere 750 (John Deere, Moline, Illinois) no-till drill in 19 cm rows, 70 kg N ha^{-1} as urea was placed in 38 cm bands and 6 kg N and 11 kg P ha^{-1} as monoammonium phosphate were placed with the seed. Nitrogen rates may have been

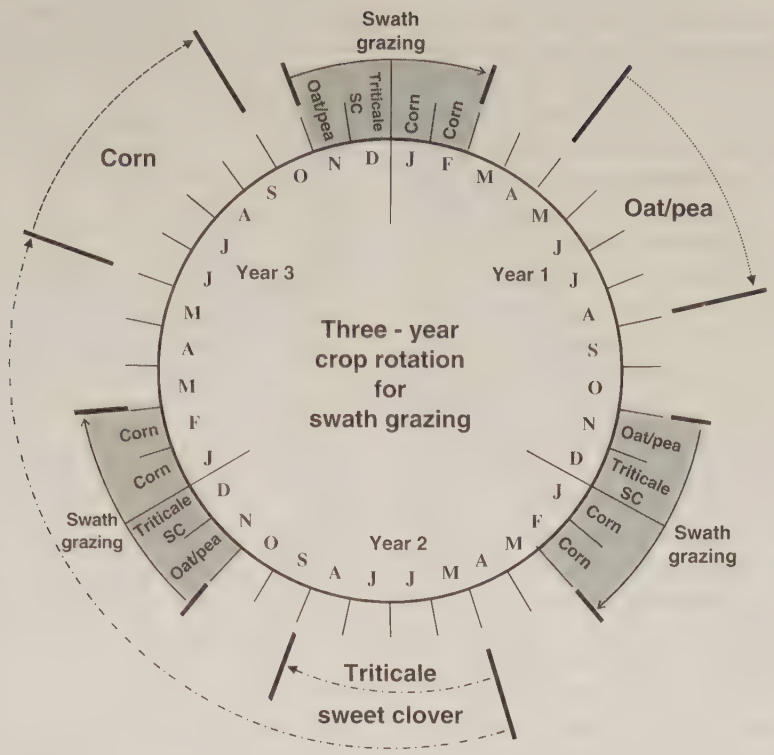

Figure 1. A 3-year cropping system (oat/pea–triticale/sweet clover–drilled corn) with all crops present each year to provide a consistent within-year winter grazing regime for dry gestating beef cows. Cows swath graze oat/pea first, then triticale/sweet clover (SC), and drilled corn last.

less than those used in traditional crop production, since we wanted to take advantage of the legumes in the cropping system.

Total above-ground dry matter production (TDM) for forage and grain and straw or stover production was determined by taking two 0.35 m^2 samples from treatments IP and R, and six 0.35 m^2 samples, one from each of the six grids, in the L treatment. Oat/pea and triticale samples were taken when the grain was physiologically mature (early to mid-August). Corn samples were taken about 1 week after the first frost (late September). After samples were taken, field size equipment was used to swath and combine oat/pea and triticale plots for grain, while corn was swathed for forage. Samples for TDM were dried at 60°C for at least 48 h, weighed, and threshed to measure grain yields for oat/pea and triticale. Straw or stover production was calculated by subtracting the grain yield from the TDM. Grain, straw or stover, and forage were ground to pass through a 1 mm sieve for laboratory analysis. Sweet clover and crop regrowth were not measured.

Ground samples were analyzed for total N and P according to procedures described by Parkinson and Allen[13] and Bowman[14]. Protein production per unit area was calculated by multiplying N concentration by 6.25 to convert N concentration to protein, then multiplying the protein concentration by TDM, grain, straw or forage production. The P production was calculated by multiplying P concentration by TDM, grain, straw or forage production.

Soil water content was determined using neutron scatter techniques. Soil water content was determined at the mid-point of each 30 cm increment to a depth of 1.8 m. Access tubes were placed in two of the six grids in each pasture on the L treatment, and one tube in each of the IP and R treatments for each pasture. Soil water content was determined at seeding and harvest for each crop. Crop water use was calculated by subtracting soil water content at seeding minus soil water content at harvest plus the precipitation received from seeding to harvest. Runoff and deep soil water percolation were assumed to be negligible. In each grid where soil water content was measured, water-use efficiency (WUE), an estimate of the quantity of forage produced per unit of water, was calculated by dividing forage production by crop water use. The N contribution to protein production from fertilizer was calculated based on the N concentration of the forage and the quantity of N provided by the fertilizer. This was based on the assumption of 100% fertilizer efficiency, which is difficult to achieve. The remainder of the protein production was inherent to the cropping system; which includes a combination of factors such as legumes in the system and decomposition of previous perennial grass, above-ground and below-ground residues, and animal and crop wastes.

Results and Discussion

Growing season precipitation (May through September) was 169% in 1999, 103% in 2000, 131% in 2001 and 57%

in 2002 of the long-term average of 29.4 cm (Table 1). Monthly precipitation for the 4 years was variable, with precipitation in May ranging from 1.3 to 16.8 cm and that in August ranging from 0.0 to 17.0 cm. The above-average precipitation in May of 1999 benefited initiation of the research. Precipitation provided moisture for ample growth of perennial vegetation prior to herbicide applications, which resulted in good perennial control and ample moisture to germinate oat/pea, triticale/clover and corn seeds.

Total above-ground dry matter, grain and straw/stover production for the 4 years was influenced by precipitation (Fig. 2). In 1999, no significant differences occurred for oat/pea, triticale/clover or corn due to the IP, R or L treatments, indicating that each pasture was relatively uniform. This would be expected since the treatments were not in place the previous year. After the cropping system treatments were in place and cattle grazed during the winter of 1999–2000, crop production trends due to IP, R and L treatments began to become evident for oat/pea and triticale in the 2000 crop. However, no significant treatment differences occurred for corn in 2000. If one uses R as the control for a crop/livestock operation, since many/most livestock producers bale straw for bedding and winter feed, then in 2000, IP significantly reduced grain and straw production for oat/pea and triticale. The L treatment did not significantly reduce grain or straw production for oat/pea, or straw production for triticale, but did significantly reduce triticale grain production when compared to R treatment.

Table 1. Monthly and long-term average precipitation for the growing season (May through September) and grazing season (October through April) for 1999 through 2003 at Mandan, North Dakota.

	Precipitation (cm)					
Month	**1999**	**2000**	**2001**	**2002**	**2003**	**Long-term average (cm)**
January	–	1.2	0.9	0.5	0.7	0.9
February	–	4.1	1.9	0.3	0.5	1.0
March	–	3.0	0.5	1.1	0.9	1.7
April	–	3.5	5.1	2.5	2.1	3.8
May	16.8	6.6	3.9	1.3	–	5.7
June	8.7	10.3	10.4	3.1	–	8.4
July	4.7	6.6	21.3	6.6	–	6.6
August	17.0	3.6	0.0	4.9	–	4.6
September	2.6	3.2	3.0	0.9	–	3.7
October	0.9	4.0	2.4	1.8	–	2.6
November	0.1	3.4	0.1	0.4	–	1.4
December	0.5	1.0	0.2	0.7	–	0.9
Total	–	50.5	49.7	24.1	–	41.3

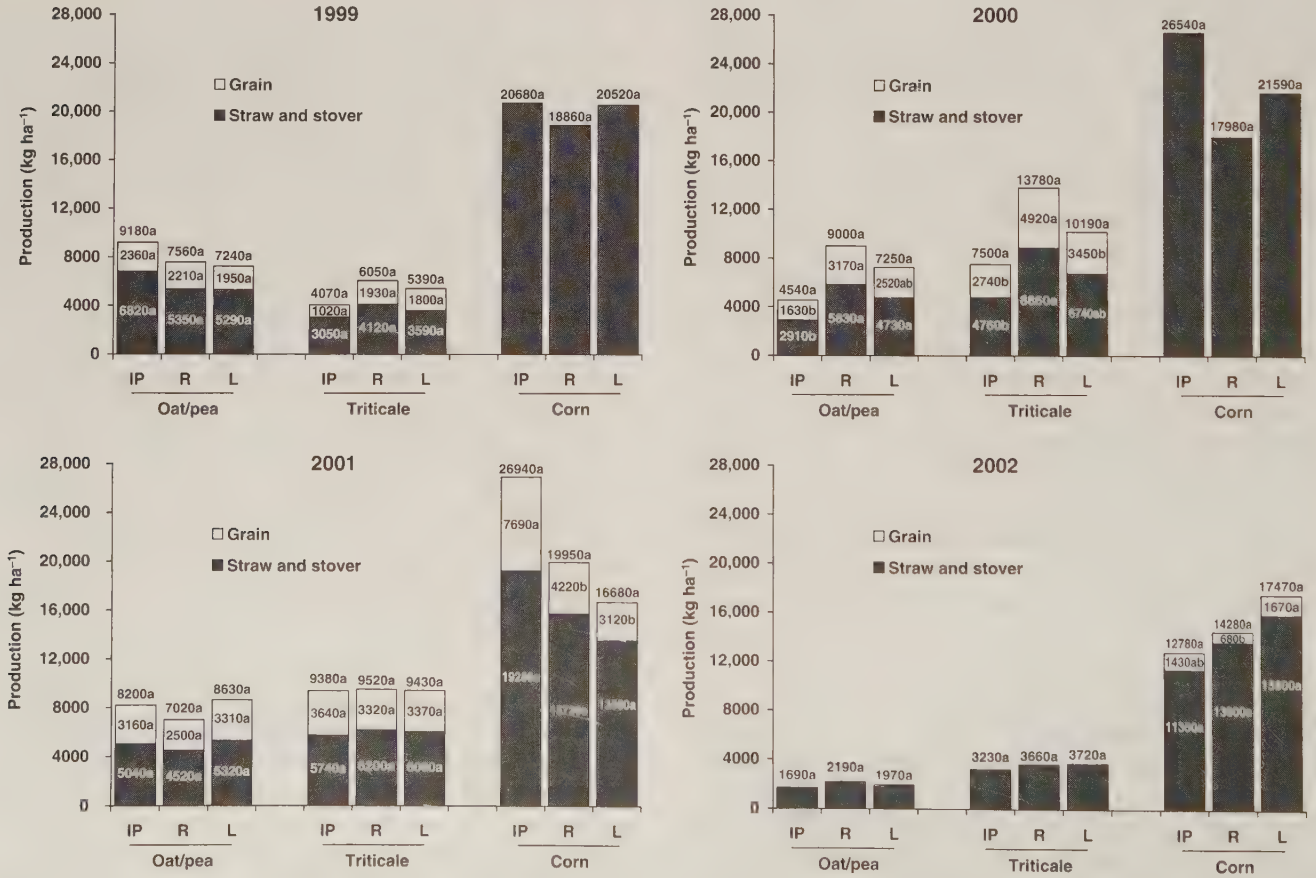

Figure 2. Total above-ground dry matter, grain and straw/stover production for straw or stover left in place with no livestock (IP), straw or stover removed (R) and straw or stover swath grazed by livestock (L) in 1999, 2000, 2001 and 2002. Treatment means within a crop and crop component followed by different letters were significantly different at the 0.10 probability level.

Table 2. Total soil water content to a depth of 1.8 m before seeding each crop for 1999 through 2002.

Crop and treatments[1]	Soil water content (cm)			
	1999	2000	2001	2002
Oat/pea				
IP	58.91a[2]	61.41a	53.87ab	55.11a
R	59.97a	65.83a	50.80b	53.85a
L	56.17a	64.07a	56.55a	52.44a
Triticale				
IP	57.92a	66.80a	54.54a	60.20a
R	57.90a	63.77a	57.34a	56.72a
L	59.71a	66.39a	57.18a	59.02a
Corn				
IP	46.02a	65.22a	60.89a	54.67a
R	50.58a	63.44a	62.89a	59.22a
L	49.56a	64.87a	59.07a	59.02a

[1] IP, Residue or stover left in place with no livestock; R, residue or stover removed; L, residue or stover grazed by livestock.
[2] Different letters in a column for a particular crop and year were significantly different at the 0.10 probability level.

Reduced production for the IP treatment may have been due to the inability of the seed openers to cut residue from the previous crop and place seed into moist soil; this failure resulted in low oat/pea and triticale plant stands (data not shown).

In the spring of 2001, residue managers were added to the no-till drill in an attempt to move about 50% of the surface residue away from the seed opener for better seed to soil contact. Better oat/pea and triticale plant stands were observed (data not shown). The IP, R and L treatments were not significantly different for oat/pea and triticale, which may have been the result of the addition of residue managers to the no-till drill (Fig. 2). Neither grain, straw nor total above-ground dry matter (TDM) production was significantly different among treatments for oat/pea or triticale crops. In 2001, corn grain responded to the additional residue in the IP treatment when compared to the R or L treatments. A possible reason for the additional corn grain on IP may be the above-average July 2001 precipitation, followed by no precipitation in August 2001. The additional residue on IP suppressed evaporation, resulting in more soil water for corn use.

For the 2002 crop, below-average precipitation after the harvest of the 2001 crop resulted in a dry spring (Table 1), but soil water content to 1.8 m was similar to that of other years (Table 2). Because of the dry conditions, oat/pea and triticale were harvested as forage in late July to salvage some forage for livestock. Oat/pea and triticale TDM were the lowest of the 4 years, with no treatment differences. Corn was able to take advantage of the average July and August precipitation to produce TDM and stover that was similar to those of other years. Corn grain production for the L treatment was greater than that of the R treatment. This may have been due to the lack of surface residue on the L treatment, which enhanced corn germination and growth during the cool June (data not shown).

For crop/livestock production systems in semi-arid regions, quality and quantity of forage produced for each unit of water used is important. Water-use efficiency (WUE) for above-ground total dry matter followed trends similar to total dry matter production (Figs. 2 and 3). As expected, no differences in WUE occurred for the baseline year of 1999. In 2000, leaving residue for oat/pea (IP) and triticale (IP) and utilizing triticale residue with cows (L) reduced WUE when compared to the R treatment, even though soil water contents at seeding were the same (Table 2). This may be due to above-average precipitation for January through May (Table 1) along with reduced plant stands (data not shown). Corn did not show WUE differences due to treatments in 2000.

In 2001, oat/pea and triticale crops did not show any WUE differences due to treatments, but corn had greater WUE on the IP treatment when compared to the L treatment (Fig. 3). Corn appears to respond to additional residue more favorably than oat/pea or triticale crops. The above-average precipitation in July (Table 1) along with the additional residue for the IP treatment suppressed evaporation of soil water in August and improved TDM per unit of water (Fig. 3).

For 2002, no WUE differences due to treatments occurred for oat/pea, triticale or corn (Fig. 3). The lack of precipitation in May and June (Table 1) reduced the WUE of oat/pea to a greater degree than that of triticale or corn. Corn WUE may have been influenced by the average precipitation in July and August. In general, corn was at least 1.5 times more efficient in using water to produce dry matter than either oat/pea or triticale. Also, oat/pea, triticale and corn, when averaged over years, were more efficient in using water to produce dry matter and forage when compared to a spring wheat crop for grain[15].

Protein production is an important factor in crops that are used for winter swath-grazing livestock[16]. In 1999, protein production for total dry matter, grain and straw/stover were not different within each crop among IP, R and L treatments (Fig. 4). This should be expected since treatments were not in place until the 2000 crop. In 2000, protein production for the IP treatment was less in oat/pea total dry matter and straw when compared to the R and L treatments. Since protein production is a function of crop production and protein concentration, this was the result of lower total dry matter and straw production for the IP treatment (Fig. 2). In triticale for 2000, grain protein production for the IP and L treatments was lower than that for the R treatment (Fig. 4). This was because of lower triticale grain production. No differences in protein production occurred for corn in 2000. In 2001, corn was the only crop to have protein production differences among treatments. The IP treatment (815 kg ha^{-1}) had about twice the grain protein production as the R (432 kg ha^{-1}) and L treatments (323 kg ha^{-1}). This was due to greater grain production (Fig. 2). The greater protein production for the

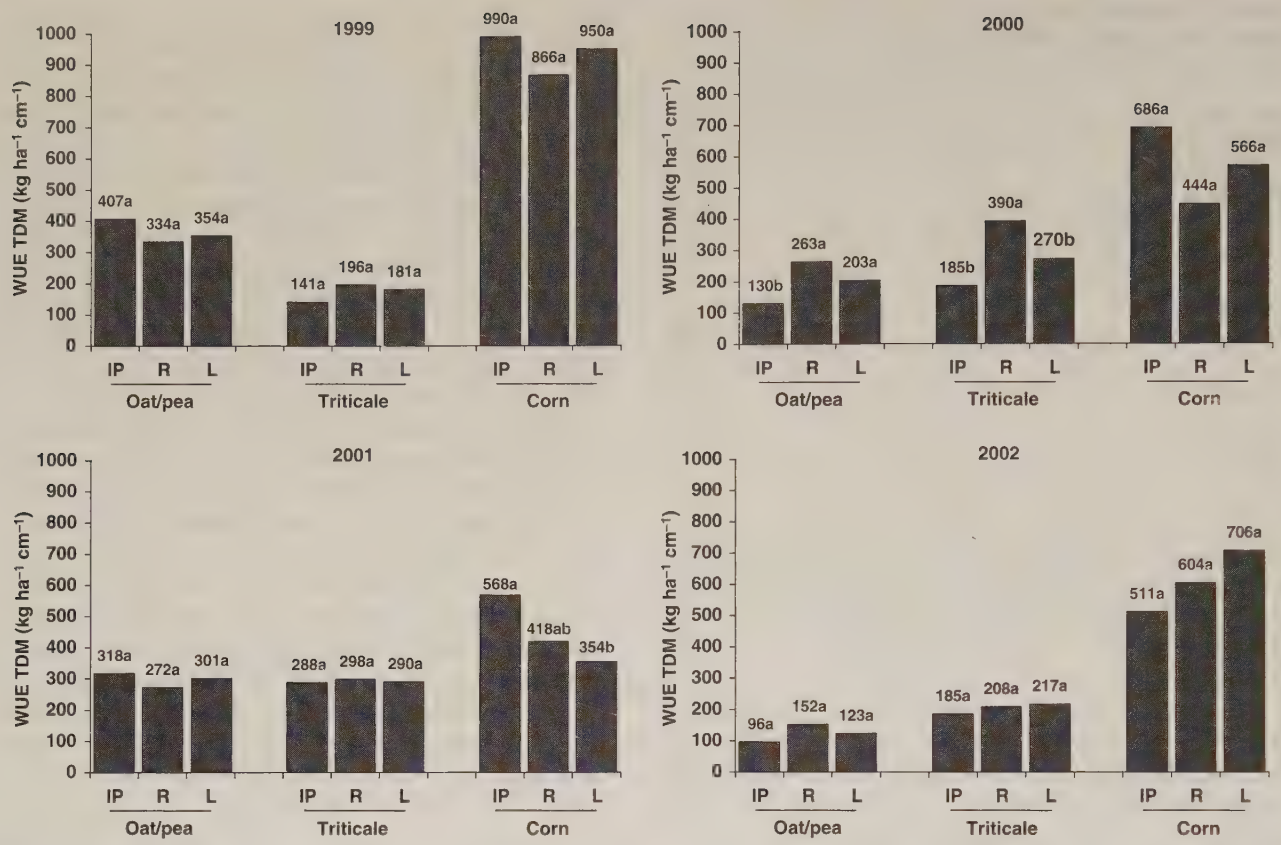

Figure 3. Water-use efficiency (WUE) for total dry matter (TDM) or forage production, as influenced by straw or stover left in place with no livestock (IP), straw or stover removed (R) and straw or stover swath grazed by livestock (L) in 1999, 2000, 2001 and 2002. Treatment means within a crop followed by different letters were significantly different at the 0.10 probability level.

IP treatment grain also resulted in greater total dry matter protein production when compared to the R and L treatments. The IP treatments for oat/pea and triticale in 2002 had less protein production than the R or L treatments (Fig. 4). This may have been due to the cool 2002 June along with the additional surface residues for the IP treatment. Greater protein production for the L treatment in corn followed trends similar to those for grain production (Fig. 2).

For dry bred gestating beef cows, P is a critical element and should not be less than 0.12%[17]. Crop P production is a function of P concentration and crop yield. In 1999, crop P production should not have been different, since treatments were not in place until the 2000 crop (Fig. 5). No explanation can be given as to why P production for the triticale IP treatment was so low. Phosphorus production for 2000, after treatments were in place, was lower in the IP treatment when compared to the R treatment for oat/pea and triticale crops. Triticale also showed a decrease in total P production for the L treatment (16.7 kg ha^{-1}) when compared to the R treatment (22.3 kg ha^{-1}). No differences were evident for corn in 1999 or 2000, but in 2001, the IP and L treatments had less P production than the R treatment for stover. This may have been due to the dry August (Table 1) as evidenced by the IP treatment, which had greater surface residue to reduce evaporation from the soil surface. The surface residues on the IP treatment insured soil water for grain production, resulting in greater P production for grain than the R or L treatments (Fig. 5).

Since protein is such an important factor for livestock production and N for crop production, we attempted to partition the source of N with respect to the amount originating from fertilizer and the amount inherent to the cropping system (Fig. 6). Inherent cropping systems N in our research could have been from a combination of factors, such as legumes in the system, animal waste and decomposition of perennial grass below and above ground residue, as well as crop residues not used by livestock. Averaged over 4 years, protein N originating from fertilizer, if for system exploration purposes we assume little or no losses due to volatilization or leaching occurred (which is unlikely), would have accounted for 420 kg protein ha^{-1}. Any protein production above that amount would have originated from the system. About one-third of the oat/pea and triticale protein production was derived from the system (Fig. 6). We are not sure why the IP treatment for triticale derived such a small amount of N from the system, but part of the reason may be the greater quantity of crop residue when compared to the R or L treatments. Greater residue would result in increased N immobilization during residue decomposition. Visually, we

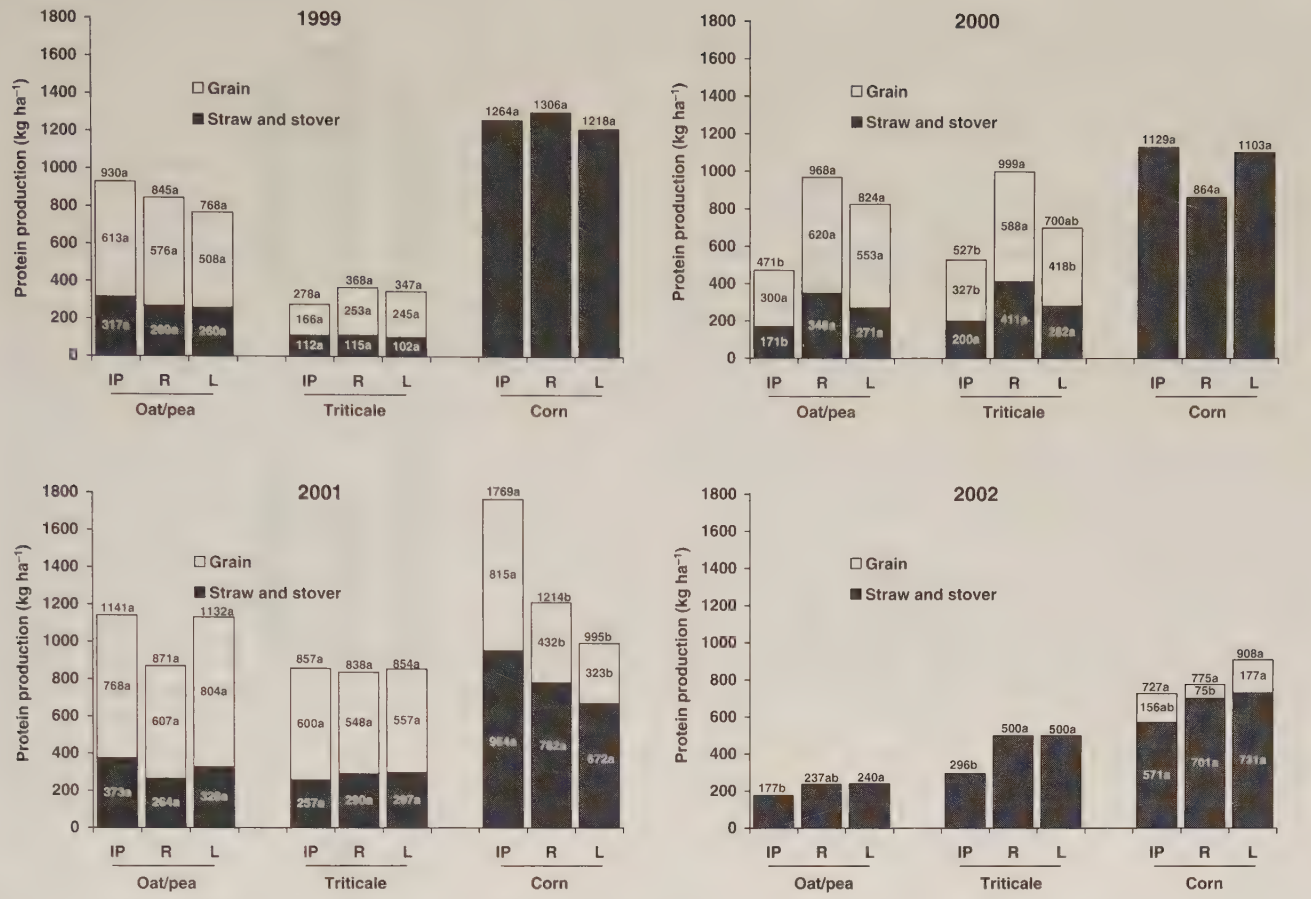

Figure 4. Protein production for total dry matter, grain and straw/stover when straw or stover is left in place with no livestock (IP), straw or stover removed (R) and straw or stover swath grazed by livestock (L) in 1999, 2000, 2001 and 2002. Treatment means within a crop and crop component followed by different letters were significantly different at the 0.10 probability level.

have noticed that the sweet clover stands in the IP treatment, since 1999, have been less than those in the R or L treatments, and the differences in stand may have some influence on the quantity of N supplied by sweet clover to the triticale crop. For corn, at least 60% of the total protein production was derived from the system. At the present time, we do not fully understand the N contribution of pea or sweet clover under-seeded in the triticale, or the interactions of crop sequences and livestock to succeeding crops; therefore, we were not able to partition the system to determine protein contributions from pea or clover. Nor do we fully understand the impacts of livestock on the L treatment. In 2002, production data for oat/pea and triticale suggested little or no influence from livestock on the L treatment, but the trend for corn shows more production from the L treatment when compared to the IP or R treatment. We are not sure of the reason for this trend, but we feel it is real and more than 4 years of research may be needed to sort out the influences of livestock on crop production.

Conclusions

Successful integrated crop/livestock systems require multi-disciplinary team efforts and a well-thought-out system. A key factor in determining the type of crops to grow is the type of animals and the stocking rate that will be used in the system, and the time of the year crops will be used. With adequate modifications to no-till seeding equipment, oat/pea and triticale crops may not be as sensitive to remaining crop residue or livestock as corn. Our data suggest that corn grain production and protein production may be enhanced with increased crop residue. We feel that legumes are beneficial to the system, but long-term data are needed before their true value as N contributors to the system, as well as their influence on soil and water resources, can be determined. To reduce input costs successfully, crop/livestock systems require additional management inputs for the crop as well as the livestock enterprise. Diverse cropping systems for forage and grain production that include cool- and warm-season annual crops, as well as biennial legumes, provide researchers an opportunity to use crops that can take advantage of erratic precipitation frequency and distribution in the northern Great Plains.

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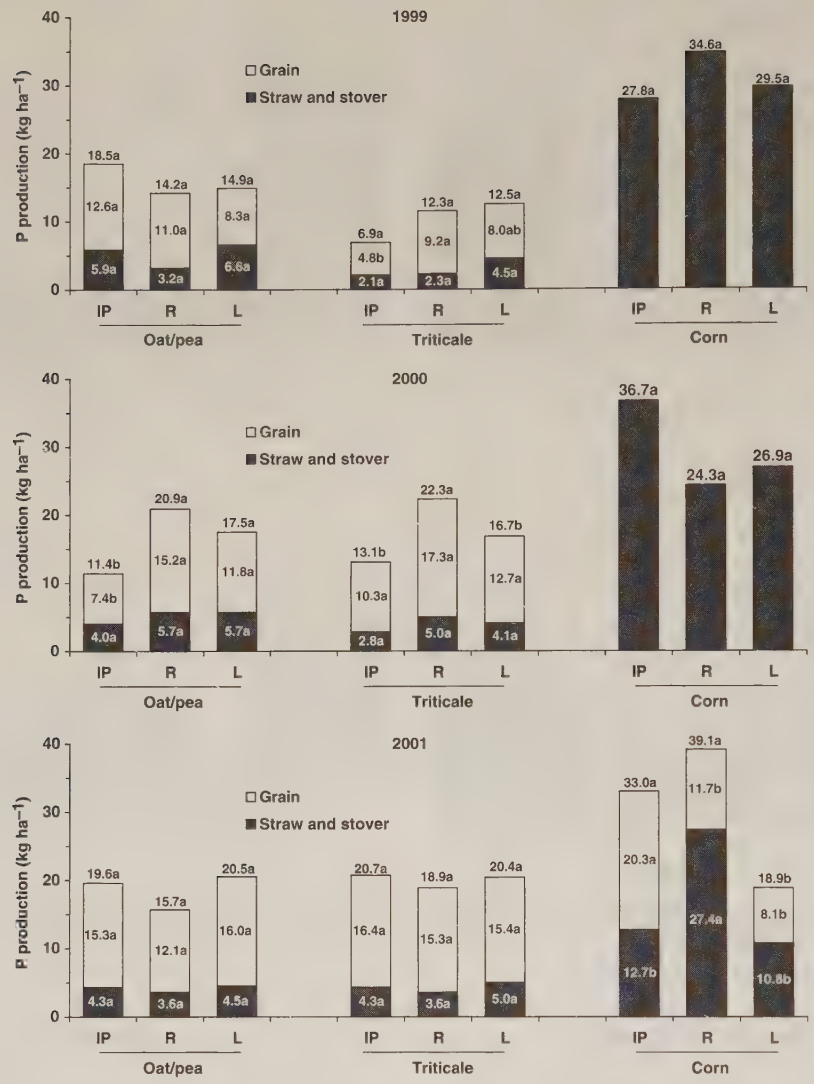

Figure 5. Phosphorus production for total dry matter, grain, and straw/stover as influenced by straw or stover left in place with no livestock (IP), straw or stover removed (R), and straw or stover swath grazed by livestock (L) in 1999, 2000, and 2001. Treatment means within a crop and crop component followed by different letters were significantly different at the 0.10 probability level.

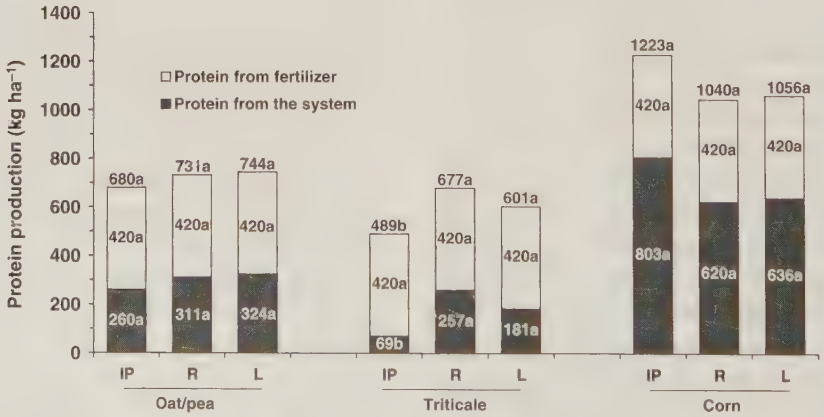

Figure 6. Four-year average protein production source as influenced by straw or stover left in place with no livestock (IP), straw or stover removed (R) and straw or stover swath grazed by livestock (L). Treatment means within a crop and crop component followed by different letters were significantly different at the 0.10 probability level.

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An integrated approach to crop/livestock systems: Wintering beef cows on swathed crops

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Abstract

Grain and livestock production have gradually been separated, as farmers have tended to specialize in one or the other. Some producers and scientists are beginning to question whether this is the best approach. An integrated crop/livestock project was initiated in 1999 to investigate potentially beneficial synergies to both enterprises. The cattle portion of this project involved wintering dry pregnant cows on swathed crop residue and drilled corn produced in a 3-year crop rotation, with all crops present each year. Swath grazing was initiated in mid-November of 1999, 2000 and 2001, and terminated in mid-February each year. Two replications of ten Hereford cows were rotationally grazed on swathed oat/pea and triticale crop residue and swathed drilled corn (RGSC). Comparison treatments were: cows grazing swathed western wheatgrass (SWWG) and cows fed hay in a drylot. Cows on the RGSC treatment were also fed a 20% crude protein supplement of oat/pea and triticale grain. Drilled corn was swathed in late September and western wheatgrass in early October. Three-year average winter-long weight gains for the RGSC cows were slightly lower ($P < 0.10$) than those for drylot cows. Body condition scores generally followed the same pattern as weight gain data. Reproductive and calf performance data were not significantly different among wintering treatments. Average daily feed costs per cow over the three winters were US$0.49, 0.65 and 0.73 for RGSC, SWWG and baled hay in a drylot, respectively, providing a potential daily savings of US$0.24 per cow with the RGSC treatment compared to bale feeding in a drylot. Swath grazing did not appear to have any adverse affects on mid-aged beef cow performance and could potentially reduce winter feeding costs and manure handling problems. The main problem with swath grazing is potentially deep snow and icing of the swaths.

Key words: drilled corn, triticale straw, oat/pea straw, dry pregnant cows

Introduction

During the last quarter of the 20th century, farmers gradually became more specialized, with many focusing on only one or two crops[1]. There is mounting evidence that this approach is neither profitable for producers nor good for the environment[2]. According to Brown[3], an ecological rather than a factory approach to agriculture is needed. In the future, new technologies will have to conform to the environments where they are used, not dominate them[4]. A more sustainable system requiring minimal amounts of pesticides and fertilizers would decrease production costs and minimize adverse environmental effects[5,6]. Crop rotations that include legumes, in concert with no-till seeding techniques, would enhance production sustainability and profitability[6]. In Europe an integrated approach to crop production, which uses less intensive management and crop rotations, has reduced fertilizer and pesticide inputs[7,8].

More complementary production systems that include both crops and livestock provide the option of marketing grain through livestock and facilitate a more efficient nutrient cycling system[9]. A unique research project integrating both crops and livestock in a whole-farm system has been developed for use in southwest Virginia[10]. The system emphasizes crop rotations, conservation tillage,

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cover crops, integrated pest management, and grazing and forage management. Related research involved development of conception to slaughter forage systems for beef cattle[11–13]. Integrating wheat production and sheep grazing has produced higher levels of both soil N and water-stable aggregates[14]. In Australia, an integrated wheat–sheep system, consisting of short-term (1–3 year) pasturing of annual legumes established with wheat, was used effectively in a variable (20.4–50.8 cm) annual precipitation zone[15]. Integrating dryland crop and livestock production in the Great Plains may offer similar benefits to both crops (soils) and livestock[16].

The most expensive aspect of a beef cow operation is the wintering of dry pregnant cows. Using annual crops or crop residues for onsite swath grazing may allow producers to reduce winter feeding costs, while animal activity and deposition of wastes directly on the land may be beneficial to soils and subsequent crop production. Wintering cattle on pastures or rangelands is less widely practiced now than it was before the winters of 1867–1868 and 1889–1890, when cattlemen suffered extensive animal losses because of severe blizzards and the lack of reserve feed supplies[17]. In Iowa, smooth bromegrass and a tall fescue–alfalfa mixture have been stockpiled (not grazed or hayed in summer) and used successfully for winter grazing by dry pregnant beef cows[18]. Berseem clover has also been stockpiled for use as a supplement for cows strip grazing corn crop residue in Iowa[19]. Body weight changes were comparable between cows wintered on stockpiled berseem clover and corn crop residue and cows fed hay in a drylot. In the northern Great Plains, grazing lands may be covered with snow for much of the winter, making it very difficult for cows to graze standing forage. Barley chaff left in swaths after harvesting has been used successfully by Canadian producers to winter beef cows[20]. Since 1978, Canadian researchers and producers have investigated the use of various small grain crops, such as oats[21], barley, fall rye and winter triticale, for winter swath grazing[22]. For a variety of reasons, swath grazing has had very limited use in the US. Although cattle can graze swaths through as much as 50.8 cm of snow[23], crusted snow and ice can be a problem, especially in the northern Great Plains. However, in eastern Colorado, foxtail millet was swathed in the early milk stage in late July, and used for fall grazing in November and December[24]. Cows grazing swathed millet and cows fed millet in a drylot had similar performances. In the Nebraska Sandhills, weanling calves have been wintered on swathed wet meadow forage[25]. Lack of information on swath grazing in the northern Great Plains convinced us that further research was needed to provide producers with a low-cost wintering alternative to drylot bale feeding.

The objectives of this research were: (1) to develop a 3-year crop rotation that would be designed to minimize the use of purchased inputs, such as nitrogen fertilizer and pesticides; (2) to produce grain that could be marketed directly or fed to livestock and marketed indirectly; and (3) to provide swathed forage for wintering dry pregnant beef cows. The focus of this paper is on the winter performance of pregnant beef cows rotationally grazed on triticale straw, oat/pea straw and swathed drilled corn.

Materials and Methods

A 3-year integrated crop/livestock project was initiated in the spring of 1999. This research included two replicates of a 3-year crop rotation consisting of oat/pea (*Avena sativa* L./*Pisum sativum* L.) in year 1; triticale/sweet clover (*Triticum aestivum* × *Secale cereale/Melilotus officinalis* L.) in year 2; and corn (*Zea mays* L.) seeded with a no-till drill in year 3. All three crops were present in both replicates each year. The oat/pea and triticale/sweet clover crops were harvested for grain with the straw spreader removed from the combine, so the straw and chaff would drop in a swath to facilitate winter grazing. Chaff placement in the swath was generally below the straw. The drilled corn was swathed in mid-September in 1999 and late September, near the first frost, in 2000 and 2001.

Rotationally grazed oat/pea and triticale crop residue and swathed drilled corn (rotationally grazed swathed crops; RGSC) plus supplemental harvested grain represented one cow wintering treatment. The performance of cows on this treatment was compared to that of cows grazing swathed western wheatgrass {[*Pascopyrum smithii* (Rydb.) Love]; SWWG} and cows fed medium-quality mixed grass hay in a drylot (control treatment). There were two replications of each of the three treatments. Ten 4–6-year-old Hereford cows, bred to calve in late March, were assigned to each treatment replication, for a total of 20 cows per treatment. Each winter experiment was started with 20 dry pregnant cows per treatment; cows used in previous years that were open, aborted or calved very late were eliminated. Initial cow weights in 1999, 2000 and 2001 averaged 541, 574 and 599 kg, respectively. Wintering treatments were initiated on 12, 24 and 8 November 1999, 2000 and 2001 and concluded on 17, 15 and 20 February 2000, 2001 and 2002, respectively. After the winter trials were completed, cows on all three treatments were maintained together and received medium-quality mixed grass hay during the remainder of the winter and native pasture during the summer.

In 1999, cows on the rotationally grazed crops treatment were initially grazed on triticale crop residue, but in 2000 and 2001 they were initially grazed on oat/pea residue. Each year, cows on the RGSC treatment grazed drilled corn last. Total grazing days and the days on oat/pea and triticale crop residues and swathed drilled corn for each year are shown in Table 1. Access to both the RGSC treatment swaths and the western wheatgrass swaths was controlled by an electric fence consisting of a 'polywire' and portable fence posts. Fences were placed at right angles to the swaths and were moved to provide cows with fresh feed on a daily basis. Cows had access to fresh water from

Table 1. Grazing days that cows on the rotationally grazed crops treatment spent on each crop during each study year.

Year	Triticale residue	Oat/pea residue	Swathed corn	Total grazing days
1999–2000	25	21	51	97
2000–2001	16	19	48	83
2001–2002	22	21	61	104
3-year average	21	20.3	53.3	94.7

'frost-free' water fountains. Cows on the RGSC treatment were also provided a daily supplement, consisting of a mixture of dry-rolled oat/pea and triticale grain harvested from the study plots. Grains were mixed in proportions to provide a 200 g kg^{-1} crude protein supplement, which was fed at variable rates, according to perceived animal needs, rather than on a constant basis. In 2000–2001, due to poor swathing conditions and extremely cold weather in November and December (Fig. 1), cows grazing swathed western wheatgrass were also provided the same supplement as the RGSC treatment cows, at the rate of 1.6 kg day^{-1} (as fed basis). Trace mineralized salt containing 96–98.5% salt, 0.35% zinc, 0.34% iron, 0.20% manganese, 0.033% copper, 0.007% iodine and 0.005% cobalt (Akzo Salt Inc., Clarks Summit, Pennsylvania, USA) was available to all groups at all times.

Cows were weighed following an overnight stand without feed or water at the beginning and end of each of the three trials. Intermediate weights were taken after grazing the oat/pea and triticale residue. Visual condition scores, based on a scoring system of 1 for emaciated and 9 for extremely fat, were recorded by three individuals at the beginning and end of the wintering period each year. An average of the three individual scores was used for statistical analysis. Birth dates and weights were recorded at calving, and calf weights were recorded at weaning. Swathed forages were sampled near the time they were swathed or harvested. During the grazing period, swath samples were taken at weekly intervals; we attempted to sample the same plant parts being selected by the cows. Hay bales fed to cows in the drylot were sampled with a coring device on a weekly basis. All forage samples were analyzed for nitrogen (N), neutral detergent fiber (NDF), acid detergent fiber (ADF), true *in vitro* dry matter digestibility (IVDMD) and phosphorus (P). Nitrogen was determined with a Carlo Erba Model NA 1500 Series 2 N/C/S analyzer (CE Elantech, Lakewood, New Jersey, USA) and crude protein (CP) was calculated by multiplying N by 6.25. Neutral detergent fiber, ADF and IVDMD were determined according to procedures described by Goering and Van Soest[26]. Neutral detergent fiber concentration in forage samples and in the residue following an *in vitro* fermentation was determined with an ANKOM fiber analyzer (ANKOM Technology, Macedon, New York, USA). Rumen fluid for the *in vitro* digestion procedure was

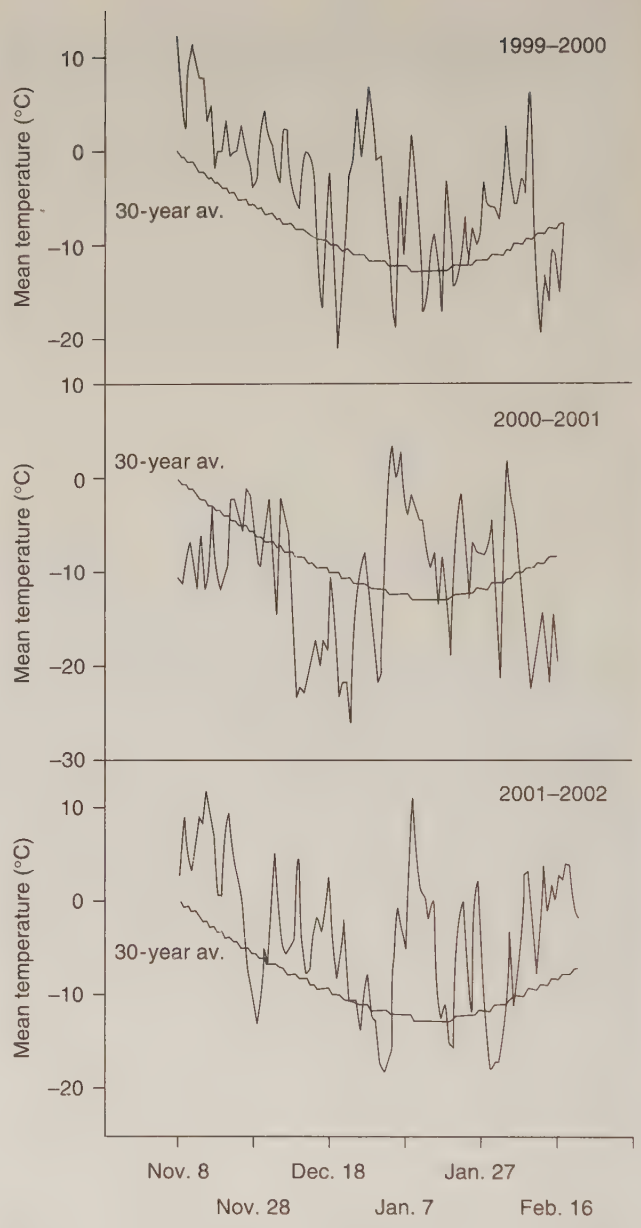

Figure 1. Average daily temperatures for November, December, January and February of 1999–2000, 2000–2001 and 2001–2002 compared to 30-year average temperatures for these months.

obtained from a mature Hereford steer. *In vitro* true digestibility was determined on forage samples by measuring NDF on the residue following a 48-h fermentation[27], instead of determining apparent digestibility by following the fermentation with a 48-h pepsin digestion[28]. Acid detergent fiber was also determined with an ANKOM fiber analyzer. Phosphorus was determined with a Quikchem 8000 continuous flow autoanalyzer (Lachat Instruments, Milwaukee, Wisconsin, USA). Production costs were determined for drilled corn and swathed western wheatgrass, and these values were used in determining daily feeding costs for each of the three winter treatments.

Animal performance data were analyzed using SAS MIXED procedures[29], with treatments and years considered

Table 2. Average daily gains (ADG) when cows on the swathed crops treatment were grazing crop residue and swathed corn, winter-long average daily gains (ADG) and winter-long weight changes (WC) ± SE, of cows during 1999–2000, 2000–2001 and 2001–2002, and for all 3 years.

	Swathed crops			
Treatment[1]	Crop residue ADG (kg day^{-1})	Swathed corn ADG (kg d^{-1})	Winter-long ADG (kg day^{-1})	Winter-long WC ± SE (kg)
1999–2000				
Hay in drylot	0.45^{a}	0.14^{b}	0.29^{b}	28.0^{b} (4.3)
RGSC	0.41^{a}	0.72^{a}	0.57^{a}	55.2^{a} (4.3)
SWWG	0.56^{a}	0.15^{b}	0.34^{b}	33.4^{b} (4.3)
2000–2001				
Hay in drylot	0.40^{a}	0.59^{a}	0.51^{a}	42.1^{a} (3.4)
RGSC	−0.51^{c}	0.32^{ab}	−0.03^{b}	−2.8^{b} (3.4)
SWWG	−0.03^{b}	−0.06^{b}	−0.05^{b}	−4.1^{b} (3.4)
2001–2002				
Hay in drylot	0.56^{a}	0.21^{ab}	0.36^{a}	37.1^{a} (4.1)
RGSC	−0.02^{b}	0.53^{a}	0.30^{ab}	31.5^{ab} (4.0)
SWWG	0.50^{a}	0.00^{b}	0.21^{b}	22.3^{b} (4.1)
3-year means				
Hay in drylot	0.47^{a}	0.31^{b}	0.38^{a}	35.7^{a} (2.3)
RGSC	−0.04^{b}	0.52^{a}	0.28^{b}	28.0^{b} (2.3)
SWWG	0.34^{a}	0.03^{c}	0.17^{c}	17.1^{c} (2.3)

[1] RGSC, rotationally grazed swathed crops; SWWG, swathed western wheatgrass.
Least squares means within a year and column with different superscripts differ at $P < 0.10$.

fixed effects. Least squares means were separated by the SAS PDIFF option.

Results

Weight change

During the first winter (1999–2000) of swath grazing, when cows on the RGSC treatment were grazing crop residue, average daily gains (ADGs) were not significantly different among the three treatments (Table 2). However, during the last 51 days (Table 1), when cows on the RGSC treatment were grazing swathed corn, their ADGs were significantly higher than those of drylot or SWWG cows (Table 2). For the entire winter period, cows on the RGSC treatment had the highest ADG ($P < 0.10$).

In 2000–2001, when the RGSC cows were grazing crop residue, their ADGs were lower ($P < 0.10$) than either drylot or SWWG cows (Table 2), but when they were grazing swathed corn their ADGs were not different from either of the other treatments. Winter-long weight changes were −2.8 and −4.1 kg for RGSC and SWWG cows, respectively, while drylot cows gained 42.1 kg (Table 2).

For 2001–2002 and the 3-year average, the RGSC cows had lower ADG during the crop residue grazing period and higher ADG ($P < 0.10$) during the swathed corn grazing period than cows grazing SWWG. Winter-long weight gains for RGSC cows were not different ($P > 0.10$) from drylot cows in 2001–2002, but averaged slightly lower ($P < 0.10$) than drylot cows over the 3 years.

Condition scores

Initial condition scores, based on a scale of 1–9, were in the mid-5 range for 2 out of 3 years and for the 3-year average (Table 3). In 2000–2001 initial condition scores were 6.0. Final condition scores differed slightly from initial scores, but there were small differences in 1999–2000, when condition scores for RGSC cows increased ($P < 0.15$) more than those for cows on the other two treatments (Table 3).

Initial and final condition scores did not differ significantly in 2000–2001, but condition score changes tended to decline for RGSC and SWWG cows in both 2000–2001 and 2001–2002. For the 3-year average, the SWWG cows had a slight ($P < 0.15$) drop in condition score and the other two treatments had slight increases (Table 3).

Calving performance

There were no significant differences among calf data from cows on the three winter treatments for any of the three years (Table 4). Birth day of year (DOY) on the three treatments ranged from 92.8 to 94.0, 94.8 to 102.4 and 97.6 to 100.4 in 2000, 2001 and 2002, respectively.

Average birth weights for all treatments and all years ranged from 39 to 43 kg, which represents an adequate weight and does not indicate any nutritional problems. Weaning weights also did not differ significantly, although there were some numerical differences among treatments and years, but the 3-year averages for cows that were used for all 3 years were 216.9, 207.4 and 213.3 kg for drylot, RGSC and SWWG cows, respectively.

Table 3. Cow condition scores[1] for winter studies beginning in November and ending in February of 1999–2000, 2000–2001 and 2001–2002 and for all three winters.

Treatment[2]	November condition score	February condition score	Condition score change ± SE
1999–2000			
Hay in drylot	5.2[a]	5.5[b]	0.3[b] (0.09)
RGSC	5.4[a]	6.1[a]	0.7[a] (0.09)
SWWG	5.5[a]	5.7[b]	0.2[b] (0.09)
2000–2001			
Hay in drylot	6.0[a]	6.0[a]	0.0[a] (0.12)
RGSC	6.2[a]	6.0[a]	−0.2[a] (0.12)
SWWG	6.1[a]	5.9[a]	−0.2[a] (0.12)
2001–2002			
Hay in drylot	5.4[a]	5.5[a]	0.1[a] (0.08)
RGSC	5.5[a]	5.4[ab]	−0.1[a] (0.08)
SWWG	5.4[a]	5.3[b]	−0.1[a] (0.08)
All 3 years			
Hay in drylot	5.6[a]	5.7[ab]	0.1[a] (0.06)
RGSC	5.7[a]	5.8[a]	0.1[a] (0.06)
SWWG	5.7[a]	5.6[b]	−0.1[b] (0.06)

[1] Condition scores are based on a score of 9 for extremely fat and 1 for emaciated.
[2] RGSC, rotationally grazed swathed crops; SWWG, swathed western wheatgrass.
Least squares means within years and columns with different superscripts differ at $P < 0.15$.

Table 4. Cow wintering treatment effects on reproduction and calf performance for 2000, 2001 and 2002; for all the cows used over 3 years; and for only the cows that calved during each of the 3 years.

Treatment[1]	Cows calving in spring	Cows open in autumn	Birth date (DOY)	Birth weight (kg)	Weaning weight (kg)	% Bulls
2000						
Hay in drylot	19	0	94.0[a]	38.6[a]	219.4[a]	26
RGSC	19	1	92.8[a]	40.4[a]	227.4[a]	58
SWWG	19	0	93.9[a]	39.9[a]	204.0[a]	42
2001						
Hay in drylot	20	1	102.4[a]	41.2[a]	220.7[a]	45
RGSC	20	1	94.8[a]	40.7[a]	218.6[a]	50
SWWG	20	2	98.2[a]	40.5[a]	218.9[a]	50
2002						
Hay in drylot	20	2	99.2[a]	43.0[a]	198.0[a]	65
RGSC	20	0	100.4[a]	41.4[a]	180.9[a]	60
SWWG	19	1	97.6[a]	39.9[a]	197.0[a]	42
Means for all cows used in the 3 winter trials						
Hay in drylot	19.7	1.0	98.6[a]	40.9[a]	212.7[a]	46
RGSC	19.7	0.7	96.0[a]	40.8[a]	209.0[a]	56
SWWG	19.3	1.0	96.6[a]	40.1[a]	206.7[a]	45
Means for cows in all 3 winter trials that calved each year						
Hay in drylot	12	–	97.6[a]	41.2[a]	216.9[a]	42
RGSC	17	–	96.7[a]	40.7[a]	207.4[a]	55
SWWG	15	–	94.6[a]	40.4[a]	213.3[a]	36

[1] RGSC, rotationally grazed swathed crops; SWWG, swathed western wheatgrass.
Least squares means within years and columns with different superscripts differ at $P < 0.10$.

Forage quality

Forage nutritive quality data, averaged over 3 years, are shown at the time feeds were harvested and at the time they were fed, in order to determine if there were apparent nutritive quality changes between harvest and use (Table 5). Although differences in the quality of harvest and feeding samples were not analyzed statistically, because of differences in the number of samples and sampling procedure, the most consistent apparent difference seemed to be with swathed corn, which declined in IVDMD, and increased in NDF and ADF between harvest and feeding (Table 5). Differences between quality components at harvest and feeding for the other forages were less, and differences among quality components were less consistent.

At the time of feeding, triticale and oat/pea residues were clearly deficient in CP (Table 5) while swathed corn and swathed western wheatgrass were marginal for dry pregnant beef cows, according to NRC[30] requirements. The P requirement for dry pregnant cows during the middle trimester is 1.2 g kg^{-1} DM[30]. This level of P was met by swathed corn and baled hay, but was clearly deficient in swathed western wheatgrass, and triticale and oat/pea crop residues.

Swath grazing economics

Production costs for swathed drilled corn (US$300 ha^{-1}) and swathed western wheatgrass (US$83 ha^{-1}) are shown in Table 6. Costs are based on our actual expenses, local rates for custom work[31] and local land rental rates[32]. Daily feed cost per cow for the three winter treatments ranged from US$0.39 to 0.59; 0.58 to 0.76 and 0.65 to 0.80 for RGSC, SWWG and baled hay in a drylot, respectively, among the three winters (Table 7). Average costs for the three winters were US$0.49, 0.65 and 0.73 for RGSC, SWWG and baled hay in a drylot, respectively (Table 8).

Discussion

Controlled grazing of swaths

An important aspect of swath grazing is the necessity to limit animal access to swaths. If cows are allowed unlimited access to a field of swaths they will waste much of the forage by lying on it, urinating and defecating on it, and destroying the continuity of the swaths, so that snow will become mixed with the forage, making it less available for grazing. It is generally recommended that an electric fence be used to limit cow access to swaths[23,24,33]. We used a single polywire electric fence, which was supported by portable electric fence posts, that we designed for light weight and ease of relocation. Others[22] have suggested

Table 5. Mean chemical composition[1] of harvested and swathed feeds used during the winters of 1999–2000, 2000–2001 and 2001–2002.

Feed[2]	CP	IVDMD	P	NDF	ADF
	---------- g kg^{-1} DM----------				
Post harvest pre-grazing chemical composition					
Triticale residue	47.3	534.2	0.9	812.8	559.5
Oat/pea residue	50.0	509.2	0.8	800.2	594.2
Swathed corn	54.8	726.1	1.6	623.4	338.3
SWWG	69.7	576.6	1.0	692.9	471.5
Chemical composition of feeds as fed					
Triticale residue	50.1	540.2	0.9	815.4	582.7
Oat/pea residue	51.9	520.0	0.9	799.9	603.7
Swathed corn	62.5	690.3	1.4	674.8	392.5
SWWG	69.9	569.1	0.9	708.5	481.4
Baled hay	111.8	633.8	1.7	669.6	451.6
Supplement	192.1	926.9	4.5	267.2	61.2

[1] CP, crude protein; IVDMD, *in vitro* dry matter digestibility; P, phosphorus; NDF, neutral detergent fiber; ADF, acid detergent fiber.
[2] SWWG, swathed western wheatgrass.

Table 6. Production costs for drilled corn and swathed western wheatgrass.

	Application rate (kg ha^{-1})	Costs per kg (US$)	Cost per hectare (US$)	Cost per plot[1]
Drilled corn				
Seed corn[2]	53.81	1.969	105.93	180.08
Herbicide[2]			36.99	62.88
Herbicide application[3]			17.58	29.89
Custom seeding[3]			19.75	33.58
Nitrogen fertilizer[2]	146.18	0.172	25.14	42.74
Starter fertilizer[2]	56.05	0.287	16.09	27.35
Swathing[3]			17.43	29.63
Land rental[4]			61.73	104.94
Total			300.62	511.09
Swathed western wheatgrass				
Land rental[4]			41.98	255.03
Nitrogen fertilizer[2,5]	73.09	0.172	12.57	76.37
Fertilizer application[3,5]			4.40	26.70
Swathing[3]			17.28	104.98
Raking swaths[3]			7.16	43.50
Total			83.39	506.58

[1] Drilled corn plot size was 1.700 ha; swathed western wheatgrass plot size was 6.075 ha.
[2] Our actual cost.
[3] Most frequently used rates from Ackre[31].
[4] From North Dakota Agricultural Statistics 2002[32].
[5] Application rate and cost were based on an application every other year.

using rebar or fiberglass posts that are set in place by using a portable electric drill to drill holes in frozen ground. Our fence was placed at right angles to the swaths, which facilitated grazing when swaths were covered with snow[33]. We moved the fence on a daily basis to reduce feed waste and provide cows with fresh feed on a regular basis[24,33]. Klein[23] recommended using an electric fence and moving it every 7–14 days, to reduce labor while also reducing feed waste compared to giving animals total access to swaths. After 2 weeks of grazing on the same area, Klein[23] reported that forage total digestible nutrients (TDN) dropped from 60% to 46%, because cows selected the best-quality forage first, reducing the selection opportunity with each additional day on the allotment.

Weight change and condition scores

Cows averaged 21 and 20.3 grazing days per year on triticale and oat/pea residue, respectively, or a total of 41 grazing days per year on crop residue during the 3-year study. Beef cow nutrient requirements are lowest in the middle trimester when the current year's calf is weaned and the fetus for next year's calf is still small[30]. This is the time when cows should be able to maintain their weight and body condition on properly supplemented crop residue. However, Chase and Hibberd[34] have suggested that feeding low-quality native hay supplemented with 2 or 3 kg of grain formulated only to meet the protein requirements of cows may decrease forage utilization to the extent that the overall energy status of the cow is not improved. In Canada, many producers, however, are using straw and chaff supplemented with cereal grain or other high-energy concentrates to winter cows successfully according to recommendations of nutrition and livestock specialists[35–37]. During our three winter trials, when cows on the RGSC treatment were grazing crop residue they gained weight the first year, lost weight the second year and about maintained their weight in the third year (Table 2). Cows lost weight while grazing crop residue in 2000–2001 during a period of below-average temperatures (Fig. 1), when there was substantial icing of the swaths.

Despite the concerns of Chase and Hibberd[34] the experience of others suggests that providing additional grain during periods of low temperature should permit cows to maintain body weight when winter grazing crop residues. Cows in our studies on the RGSC and the SWWG treatments gained weight in two out of three winters, and in the other winter they only lost a small amount of weight. Cow condition scores changed little during our three trials (Table 3), and the changes that occurred generally reflected cow weight changes (Table 2). Body condition score or degree of fatness, coupled with changes in body weight, have been shown to provide a useful method of assessing reproductive potential in beef cows[38].

Winter grazing cows on stockpiled forages is another means of decreasing the use of harvested feeds. In one study, cows grazing stockpiled tall fescue–alfalfa, smooth-grass–red clover and corn crop residues had weight gains and body condition scores that were as high, or higher, than those of cows wintered on hay in a drylot, and required 1069, 1032 and 627 kg less hay DM/cow[18].

Table 7. Feed offered, feed refused and feed costs for the rotationally grazed crops, swathed crops and baled hay treatments in 1999–2000, 2000–2001 and 2001–2002.

Feedstuff[1]	DM offered per day (kg)	Estimated waste (%)	Days on a feed	Feed cost per cow (US$)	Feed cost per cow per day (US$)
1999–2000					
Swathed corn	37.2[2]	50	51	28.05[3]	0.29[4]
Crop residue	33.6[2]	52	46	3.36[5]	0.03[4]
Supplement	1.5	0	97	14.74[6]	0.15
RGSC total			97	46.15	0.48
RGSC average	37.2	48.5			
SWWG	16.1[7]	3	87	56.45[8]	0.58
Baled hay in drylot	14.3[9]	10	97	63.05[10]	0.65
Baled hay–RGSC diff.				16.90	0.17
Baled hay–SWWG diff.				6.60	0.07
2000–2001					
Swathed corn	46.3[2]	55	48	30.72[3]	0.37[4]
Crop residue	55.3[2]	67	35	3.36[5]	0.04[4]
Supplement	1.8	0	83	14.94[6]	0.18
RGSC total			83	49.02	0.59
RGSC average	52.1	58			
SWWG	26.1[7]	15	82	51.29[8]	0.62
Supplement	1.4	0	83	11.62	0.14
SWWG total	27.5			62.91	0.76
Baled hay in drylot	17.2[9]	15	83	66.40[10]	0.80
Baled hay–RGSC diff.				17.38	0.21
Baled hay–SWWG diff.				3.49	0.04
2001–2002					
Swathed corn	31.8[2]	40	61	31.72[3]	0.31[4]
Crop residue	44.0[2]	60	43	3.36[5]	0.03[4]
Supplement	0.45	0	104	4.99[6]	0.05
RGSC total			104	40.07	0.39
RGSC average	37.4	49			
SWWG	16.5[7]	3	86	60.53[8]	0.58
Baled hay in drylot	16.7[9]	12	104	75.92[10]	0.73
Baled hay–RGSC diff.				35.85	0.34
Baled hay–SWWG diff.				15.39	0.15

[1] RGSC, rotationally grazed swathed crop; SWWG, swathed western wheatgrass.
[2] Feed offered is based on dry matter production data from Tanaka et al.[46].
[3] Swathed corn production costs are presented in Table 6 and grazing costs are based on 93, 80 and 99 potential grazing days in 1999–2000, 2000–2001 and 2001–2002, respectively.
[4] Values are based on the total number of winter grazing days each year.
[5] Swathed crop residue was valued at US$4.00 per acre. Based on data from Popp[47].
[6] Supplement was valued at US$0.04 per pound on an 'as is' basis. Based on local grain prices in 2003.
[7] SWWG offered per day was based on dry matter yields of 2390, 3652 and 2417 kg ha^{-1} in 1999–2000, 2000–2001 and 2001–2002, respectively.
[8] Total feed cost for SWWG was based on the total study length, even though swathed western wheatgrass in treatment pastures only lasted for 87, 82 and 86 days in 1999–2000, 2000–2001 and 2001–2002, respectively. Production costs are shown in Table 6.
[9] Baled hay dry matter averaged 85, 83 and 88% in 1999–2000, 2000–2001 and 2001–2002, respectively.
[10] Baled hay was valued at US$35 per ton on an 'as is' moisture basis. Value based on data from North Dakota Agricultural Statistics 2002[48].

Calving performance

One of our primary concerns with winter swath grazing was the potential effect of a low-quality winter diet on subsequent rebreeding. Low pre-calving energy levels have been shown to have a detrimental effect on subsequent beef cow reproduction, primarily due to a longer post-partum interval before cows begin exhibiting estrus[39,40]. In our study, winter treatment did not affect birth DOY in any year. However, birth DOY was 5.2, 7.6 and 3.7 days longer, from 2000 to 2002, for cows fed hay in a drylot, RGSC cows, and cows grazing SWWG, respectively (Table 4). But 2002 DOY data included a number of cows that were not used in 2000. The 3-year DOY means for cows used during all three years were only 3.6, 3.9 and 0.7 days longer than 2000 birth DOY for drylot cows, RGSC cows and cows grazing SWWG, respectively. Low birth weights are also indicative of inadequate precalving

Table 8. Feed offered, feed refused and feed costs for the rotationally grazed crops, swathed crops and baled hay treatments averaged over 3 years.

Feedstuff[1]	DM offered per day (kg)	Estimated waste (%)	Days on a feed	Feed cost per cow (US$)	Feed cost per cow per day (US$)
Swathed corn	38.4[2]	48.3	53.4	30.44[3]	0.32[4]
Crop residue	44.3[2]	59.6	41.3	3.36[5]	0.04[4]
Supplement	1.3	0	95.0	12.35[6]	0.13
RGSC total			95.0	46.15	0.49
RGSC average	42.1	51.8			
SWWG	19.6[7]	7	85.0	56.62[8]	0.60
Supplement	0.45	0	95.0	4.37	0.05
SWWG total	20.0		95.0	60.99	0.65
Baled hay in drylot	16.2[9]	12.3	95.0	69.35[10]	0.73
Baled hay–RGSC diff.				23.20	0.24
Baled hay–SWWG diff.				8.36	0.09

[1] RGSC, rotationally grazed swathed crop; SWWG, swathed western wheatgrass.
[2] Feed offered is based on dry matter production data from Tanaka et al.[46].
[3] Swathed corn production costs are presented in Table 6 and grazing costs are based on 93, 80 and 99 potential grazing days in 1999–2000, 2000–2001 and 2001–2002, respectively.
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energy[40,41], but in our study birth weights did not differ among winter treatments in any year (Table 4).

Forage quality

Potential deterioration of swathed forages between swathing and consumption was also a major concern in this study. Swathed western wheatgrass and oat/pea and triticale crop residue did not differ consistently between harvest and feeding, but swathed corn did tend to decline in quality (Table 5). Most of the deterioration in swathed corn quality appeared to occur before feeding commenced. Weekly samples during the feeding period showed little change, therefore forage nutritive quality data (Table 5) were averaged over weeks and years rather than by week. Hitz and Russell[18] reported daily declines in IVOMD and crude protein, and increases in NDF and ADF, in smooth bromegrass–red clover, tall fescue–alfalfa and corn crop residues during the winter grazing period, but quality changes did not differ among forages. Stockpiled berseem clover was used as a supplement for cattle grazing corn crop residues, but its rapid decline in nutritive value during the winter would appear to limit its future use[19]. In a Nebraska winter swath grazing study with steer calves, Volesky et al.[42] reported that crude protein was similar for baled and swathed hay and declined little during a winter grazing period, while crude protein in standing forage declined by almost 50%.

Swath grazing economics

Winter beef cow feed costs make up a substantial portion of the annual expense of maintaining a beef cow, and it is also the most logical area where cow production costs could be reduced. Our results indicate that cows could be wintered on RGSC for an average of US$0.49 per cow per day (Table 8), which would be US$0.24 per cow per day less than the cost of wintering cows in a drylot on large bales of hay. The advantage for the RGSC treatment ranged from US$0.17 to 0.34 per cow per day among the three winter trials. Costs of wintering cows on SWWG ranged from US$0.04 to 0.17 per cow per day less than drylot feeding. Swath grazing western wheatgrass was not as efficient at lowering winter feed costs as RGSC because our western wheatgrass yields were low, ranging from 2390 to 3652 kg ha^{-1}. In addition, in 1999–2000 our grazing days were decreased because strong winds blew a substantial amount of swathed forage away, and in 2000–2001 we had to supplement cows grazing SWWG because of below-average November and December temperatures (Fig. 1). In 2000–2001, our western wheatgrass also contained some volunteer sweet clover, which decreased forage quality and reduced perennial grass yield. Munson et al.[24] reported that swath grazing costs in eastern Colorado were US$0.45 per cow per day less than the cost of bale feeding, but their bale costs were based on small, square bales instead of large, round bales, which would have raised bale feeding costs

substantially. Volesky et al.[42] reported a US$0.14 per calf per day advantage in central Nebraska for swath grazing perennial grass with weanling calves, compared to feeding calves the same forage in bales. Data from Saskatchwan indicate that 1.0 ha of corn would provide winter grazing for 2.47 cows for 100 days at a cost of $0.57 per cow per day[20] (Canadian currency). We averaged 5.29 cows ha^{-1} of corn for 100 days in our study. However, our production costs were US$300 ha^{-1} compared to $140 ha^{-1} (Canadian currency) reported by Klein[20]. Our costs for cows grazing swathed corn without supplement ranged from US$0.52 to 0.64 per cow per day, while our RGSC system costs ranged from US$0.39 to 0.59 per cow per day (Table 7). We have elected not to include in our calculations the costs of feeding bales to drylot cows or the cost of an electric fence and labor to move it daily, but Surber et al.[33] estimated bale feeding costs at US$12.35 to 24.70 ha^{-1}, based on a yield of 3.36 tonnes ha^{-1}, and swath feeding costs at US$4.94 ha^{-1}. Other cost savings for swath grazing include less wear on machinery required to bale, transport and feed hay, and minimal manure handling costs.

Forage waste

We estimated wasted forage because actual measurements would have been difficult and questionable, due to swath variability before grazing and distribution of residue after grazing, plus severe disruption of swaths by winds, especially in the first year. Estimated unused oat/pea and triticale residue ranged from 52 to 67% and estimated swathed corn waste ranged from 40 to 55%. Our intention was to allow cows to select the highest quality material available from the swathed corn and oat/pea and triticale crop residue swaths. Waste from grazing swaths of sub-irrigated wet meadow hay with calves and cows ranged from 4% to 18% over 2 years[42], which is comparable to our estimate of 7% waste for SWWG.

Although we had substantial amounts of unused corn stalks and oat/pea and triticale crop residues, they did not present a spring seeding problem because they were dispersed during the grazing process. However, since our overall goal was an improved crop/livestock production system, we considered the unused forage as a benefit not a liability. Beneficial effects of the residue include its potential to reduce wind erosion[43] and soil water loss[44,45] and to maintain or improve soil organic matter. If waste from swath grazing is a concern, swath grazing waste can be reduced by providing animals fresh swathed material on a daily basis; and if snow is a problem, cows can be returned to swathed areas in the spring for regrazing after snow melt, but while fields are still frozen[23,33].

Conclusions

Three years of winter swath grazing data suggest that properly supplemented cows swath grazed on a system of oat/pea and triticale crop residue and swathed corn, or grazed on swathed western wheatgrass, had weight changes, condition scores and reproductive performances comparable to cows fed baled hay in a drylot. Triticale and oat/pea crop residues and swathed western wheatgrass nutritive quality changed little from harvest to feeding. Swathed corn nutritive quality did appear to decline slightly between harvest and feeding, but its nutritive quality at feeding was still relatively high. Data indicate that swath grazing is a viable alternative to drylot feeding and results in lower feed costs. Feed costs for cows grazed on swathed crops and SWWG averaged US$0.24 and US$0.09 per cow per day, respectively, lower than that of cows fed hay in a drylot. The biggest concern about swath grazing seems to involve access to swaths when snow is deep or when swaths become iced over. If snow or ice becomes a problem, mechanical treatment may be necessary to temporarily assist cows in gaining access to the swathed materials. Although no manure measurements were taken during these studies, it is obvious that manure and wasted hay have to be removed from the drylot feeding area, while in pastures where swathed grazing occurred, manure and urine are already distributed on the land, where they should facilitate production of the next crop. Including cattle in a crop production system adds value and facilitates marketing grain and/or crop residue through cattle, and deposition of manure and urine directly on the land turns a potential problem into an asset.

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Farmer research: Conventional experiences and guidelines for alternative agriculture and multi-functional agro-ecosystems

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Abstract

Crop producers are challenged to operate profitably, use resources efficiently, meet high standards of quality and protect the environment, while sustaining rural economies and societies. Cropping systems are generally fine-tuned and improved through changes that have small effects which can often be verified only through research. The processes and successes of two farmer research projects were studied. Results of these studies, information from other sources and the authors' reflections on their own experiences were integrated to develop guidelines for the implementation of farmer research projects for alternative agriculture and multi-functional agro-ecosystems with diverse stakeholders. Surveys were mailed to 118 farmers currently or previously participating in a farmer research project, and to 15 advisors. Responses show that involvement in a farmer research project was profitable, stimulating, enjoyable and worthwhile, despite a substantial time requirement. Tillage and soil fertility research had greater impact on annual farm profit than research on other topics. Farmers and advisors emphasized the importance of the farmers' roles in identification of research topics, research planning and implementation, and interpretation of the results. Replicated trials conducted over 2 or 3 years were recognized as necessary to adequately verify practices for the corn–soybean rotation of eastern Nebraska, USA. Such trials may need to be complemented with alternative research approaches for improving alternative agriculture and multi-functional agro-ecosystems where knowledge about some system components is relatively scarce and there is a need to evaluate long-term effects. In conclusion, organized farmer research is an efficient means to cropping system improvement. Guidelines are given for initiation and implementation of farmer research projects.

Key words: agro-ecosystems, alternative agriculture, multi-functional, on-farm research, participatory research

Introduction

Agriculture in the US is constantly challenged to achieve greater efficiency in resource use while providing a high-quality product, protecting the environment and sustaining rural economies and societies. Farmers face an overwhelming array of information of varying quality, veracity and applicability to their particular situations, and yet information is inadequate for some decisions. At the same time, the farmer is often the most informed person about his/her operation and is best able to judge the information needs and to apply information for making improvements[1–3]. Farmers make decisions by applying

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more- or less-verified information from different sources in various ways:

- full adoption of a promoter's recommendation with little follow-up observation or evaluation;
- seeking information or advice from more- or less-objective sources;
- testing the information through whole or partial field application with close observations; and
- testing the information through replicated or non-replicated trials.

Alternative practices can be rejected as not feasible or profitable without field testing, but adoption may require better information, as the effects of changed practices are generally small. Replicated trials conducted over 2 or more years may be needed to verify the effects of alternative practices on yield and profitability in already fine-tuned cropping systems.

Farmer research is a methodological means of research conducted by farmers for discovery or production of information. Farmer research is generally:

- focused on priority information needs identified by, or with, the farmer or farmers;
- based on the farmer's experience and knowledge of his or her farming operation and situation, which is integrated with external knowledge; and
- conducted primarily by the farmer.

Farmer research becomes more effective when one or more of the following is true:

- farmers are knowledgeable about the situation;
- the problem is transparent to farmers, and the causal agents are easily observed and/or understood (e.g., farmers can conduct research on a new crop more easily than on a virus);
- the farming system is composed of diverse, non-conventional enterprises and their interactions;
- the agro-ecosystem is dynamic and requires responsive management;
- the research cycle is short; and
- there is institutional support for farmer research[1–5].

Farmer research groups provide an opportunity to 'achieve better communication and enhanced cooperation among farmers, researchers and extension educators'[6]. There is a regular flow of ideas for further improvements, a sharing of information and group participation in the interpretation of the information and its applicability. Gerber[6] wrote 'It is critical that both farmers and researchers share their interpretations with each other and with the larger community'. The flow of newly discovered information to diverse stakeholders is important, as is the conveyance from farmer research groups of their information needs to public-sector scientists[7].

The objectives of this research were to evaluate two farmer research projects and to develop guidelines for the implementation of farmer research projects for improving alternative agriculture and management for a multi-functional landscape[8], watershed or agro-ecosystem with diverse stakeholders (referred to as multi-functional agro-ecosystems in this paper). We consider alternative agricultural systems to include various non-conventional options, such as organic farming, bio-renewable agriculture and food systems, and production of specialty crops. The guidelines were developed using information from an evaluation of the processes and successes of two on-going farmer research projects in southeastern Nebraska, and insights of the authors gained from experience with these projects and through work in eastern Africa[3,4,9–11] and through study of farmer research conducted elsewhere.

Project Description and Study Design

The Nebraska Soybean and Feed Grains Profitability Project (Profitability Project) was started by educators of University of Nebraska Cooperative Extension in 1989 to enable farmer-initiated research in partnership with Cooperative Extension and private sector agronomists. Extension educators perceived a need for field-scale verification trials that address farmers' information needs and utilize their knowledge of cropping systems. In the first year, two extension educators identified and worked with 11 farmers in conducting trials. The number of farmers increased as other farmers learned of the opportunity from participating farmers and educators. The increase strained the human and equipment resources available to follow through on all research protocols. More extension educators became involved, expanding the geographic area of farmer participants. Independent crop consultants were invited to participate as advisors to design and implementation of research. Typically, about 35–40 trials have been conducted annually over an area lying in Butler, Cass, Dodge, Lancaster, Saunders and Washington counties. Each farmer selects his/her research topics. Topics are often addressed by just one farmer, but evaluated for several years. A professor emeritus of soil science assists in experimental design and data analysis on a consultancy fee basis. Farmers pay a US$150 fee to participate in the research project, but are also offered farm management consultation as well as participation in tours and meetings organized by the Profitability Project.

The Quad County (Clay, Fillmore, Hamilton and York counties) Project grew out of planting density studies conducted by the extension educator with farmers in Hamilton county in 1998; this research was extended to the other three counties in 2000 with 20 farmers and 5 extension educators and specialists participating. Farmer recruitment was similar as for the Profitability Project. A research topic in the Quad County Project may be addressed by a single interested farmer, but most research topics are addressed by several farmers over several years.

In both projects, research is conducted as replicated trials with treatments assigned more-or-less at random to blocks, such as with alternating paired comparisons. Educators or consultants conduct statistical and economic analyses of the data. Farmers and/or their advisors present their results at

a winter meeting to other participating, as well as to interested but non-participating, farmers, who discuss the interpretation and application of the results.

Questionnaires were mailed in February 2004 to all current or past participants in these projects, including 89 farmers of the Profitability Project and 29 farmers of the Quad County Project, to learn more of their perspectives and experiences. Questionnaires were also sent to the 15 research advisors who worked with these projects, including Cooperative Extension educators and consulting agronomists. The questionnaires used open-ended (OE) and close-ended (CE) questions to ask farmers for information on: research topics addressed (OE); production practices changed (CE); profit gains resulting from the research (CE); successful and unsuccessful endeavors of the project (CE); opportunities and obstacles to continued project success (OE); reasons for participating (CE); time requirements for participation and opportunities to simplify involvement (OE); and reasons for farmers quitting (CE). The questionnaires asked advisors about: successful and unsuccessful endeavors of the project and their importance (OE); opportunities and obstacles to continued success (OE); and their reasons for participating in the project (CE). Results from close-ended questions are presented as percentages or means. Results from open-ended questions were grouped into subject-matter categories, and the number of responses per category were reported.

The results of the surveys were reported and integrated with the authors' knowledge and insights gained from these and other projects[3,4,9–11], and applied to develop guidelines for implementation of farmer research projects for three crop-production situations: conventional agricultural; alternative agriculture; and multi-functional agro-ecosystems.

Results of the Surveys

Responses were received from 32 farmers of the Profitability Project, of which 25 are currently involved. The response rates were about 65% for active and 15% for no longer active farmers. Thirteen Quad County Project farmers responded, yielding a 45% response rate. All stated that they were currently active. Responding farmers had been involved with a farmer research project for 1–14 years, with a median of 4.5 years, and for 1–6 years, with a median of 4 years, for the Profitability Project and Quad County Project, respectively. Eleven of the 15 extension educators and consultants responded.

Farmers with the Profitability Project conducted trials to address 1–4 (mean = 2.1) research topics per farmer during the course of their involvement in the project. The mean for the Quad County Project, where several farmers addressed some topics, was 3.5 research topics per farmer. Research topics addressed by the 45 farmers included: 31 for planting, including row spacing, time of planting, plant density and planting speed; 30 for soil fertility management, including 9 on the use of manure or municipal biosolids; 24 for weed, insect and disease management; 13 for tillage; 3 on irrigation; and 11 for other topics. Most research topics addressed corn and soybean production.

Reasons for farmer and advisor involvement

Farmers rated profitability and being a better farmer as the most important reasons for involvement in a farmer research project (Table 1). Most enjoyed the participation and the majority responded that farmer research was a very important means to improving the area's agriculture. Most responding farmers apparently were not very concerned about neighbors' opinions of their involvement.

Advisors rated farmer research as a means to improving the area's agriculture as the leading reason for involvement (Table 2). Like the farmers, advisors enjoy the process and they believe that it helps them to be a better educator or consultant. Less important reasons were the improvement of their effectiveness and/or their businesses, and enhancement of their professional reputations.

Table 1. Importance of reasons for farmer involvement in a research project (shown as the percentage of respondents).

Reason for participation	Very important	Important	Not important
Nebraska Soybean and Feed Grains Profitability Project ($n = 32$)			
It is profitable	84	13	3
It enables better farming	81	16	3
It improves the area's agriculture	59	38	3
We enjoy it	70	27	3
It impresses neighbors	3	19	78
Quad County Project ($n = 12$)			
It is profitable	42	58	0
It enables better farming	92	8	0
It improves the area's agriculture	75	25	0
We enjoy it	58	42	0
It impresses neighbors	0	0	100

Table 2. Importance of reasons for extension educator and consultant involvement in a research project (shown as the percentage of respondents); $n = 10$.

Reason for participation	Very important	Important	Not important
It is a means to improving the area's agriculture	100	0	0
Helps to become a better educator/consultant	90	10	0
It is enjoyable	90	10	0
Enhances my professional reputation	70	20	10
Improves effectiveness or business	60	30	10

Project successes

Farmers. Based on the responses, the estimated average impact on average annual whole-farm profitability for the Profitability Project and Quad County Project, respectively, has been US$2370 and US$2209 for planting research, US$3643 and US$5338 for tillage research, US$5188 and US$3842 for soil fertility, and US$3181 and US$2813 for pest management.

Both projects have been successful in all areas that the respondents considered important. For example, identification of more profitable farming practices, good interaction with Cooperative Extension, and improved farm profitability were rated as very important objectives and as successful by 80–100% of the respondents (Table 3). Project continuity was achieved and considered important. Farmer satisfaction with the farmer research projects was high, but rated as less important with the Quad County as compared to the Profitability Project. Involvement of university research was rated as more successful with the Quad County Project than with the Profitability Project, while the opposite was true for involvement of crop consultants. Both projects successfully involved agribusiness. Farmers in both groups generally reported that development of alternative cropping systems, farm safety, and influence on agricultural policy were not relevant nor important objectives of the research projects.

Table 3. Farmer assessment of importance and achievement of successes of their farmer research project (shown as the percentage of respondents and rating).

	Success achieved (%)			Importance (mean, 1–3)
	S[1]	U	N	
Nebraska Soybean and Feed Grains Profitability Project ($n = 32$)				
Led to use of more profitable practices	97	0	3	2.9
Good interaction with extension	94	6	0	2.7
Improved farm profitability	84	6	9	2.8
Improved farmer satisfaction	84	0	13[2]	2.6
Project continuity	78	6	13	2.5
Involved university research effectively	75	6	19	2.4
Involved consultants effectively	72	9	16	2.4
Enabled farmer innovativeness	69	0	28	2.3
Involved agri-business effectively	53	6	38	2.2
Led to development of alternative cropping systems	25	6	81	1.6
Improved farm safety	25	0	72	1.6
Influenced agricultural policy formulation	16	6	75	1.6
Quad County Project ($n = 12$)				
Led to use of more profitable practices	83	8	8	3.0
Good interaction with extension	92	8	0	3.0
Improved farm profitability	75	17	0	3.0
Improved farmer satisfaction	83	0	17	2.5
Project continuity	67	0	17	2.5
Involved university research effectively	83	0	8	2.7
Involved consultants effectively	50	17	33	2.3
Enabled farmer innovativeness	92	0	8	2.7
Involved agri-business effectively	58	8	17	2.3
Led to development of alternative cropping systems	42	25	42	1.8
Improved farm safety	25	8	58	2.0
Influenced agricultural policy formulation	25	0	67	1.8

[1] Success (S), unsuccessful (U), not relevant (N), very important (3), less important (2), not relevant (1).
[2] Percentages do not always total 100% as not all farmers responded to some questions.

Additional successes rated very important by one farmer each included good interaction with other farmers and university faculty, assistance in decision making, accelerated technology adoption, improved irrigation efficiency and a better understanding of soil fertility. The only additional 'unsuccessful endeavors' reported were that not all trials produced positive information and that replicated tillage trials are difficult for farmers to conduct.

Extension educators and consultants. Advisors most frequently identified the following as successes: the reputation of Cooperative Extension is enhanced with farmers and information was gained on topics where formal research was inadequate or lacking (e.g., long-term effects of lime application, pollen drift and yield lag with Bt corn, and chloride application) (Table 4). Successes mentioned by four advisors each were increased farmer participation and farmer adoption of practices as a result of the research findings. Three respondents each reported the following successes: farmers better understand and learn to conduct their own agronomic research ('Each of the farmers has learned that they can gather information that can be used on their site; ... [We can] check to see if the claim is a real or imagined return to the farmer.'); and farmer willingness to share their information ('The level of discussion and camaraderie is higher than any large group I have encountered in agriculture.').

The most frequently mentioned unsuccessful endeavor was poor implementation of some trials. Two advisors each mentioned the following: educational tours and meetings often are not held or are poorly attended, and Cooperative Extension specialists are inadequately involved: 'We need to do a better job of connecting growers and their on-farm comparisons with university faculty' and 'We don't get much interest from specialists to be involved with the group'. Other failures to achieve full success were identified: too few of the research ideas come from farmers; farmers often lose interest; not much mutual learning among farmers on yield mapping; and inadequate publication and dissemination of the results.

Table 4. Successes achieved and not achieved identified from an open-ended question by 11 extension educators and consultants who assist in farmer research; number that named a success achieved or not achieved.

	Number
Success achieved	
The reputation of Cooperative Extension with farmers is enhanced	6
Addressed topics lacking university research	5
Farmer participation has increased	4
Farmers adopted better practices	4
Farmers better understand agronomic research	3
Farmers have learned to conduct their own research	3
Great sharing of information by farmers	3
Success not achieved	
Too many trials are not well implemented	4
Extension specialists are not adequately involved	2
Educational tours and meetings often not held or are poorly attended	2

Successful initiation of a farmer research project

Advisors identified several elements important to the successful start-up of farmer research projects. Starting with the right farmers was seen as essential to successful initiation: 'farmers who are respected in the community and who are willing to share/promote/tell the story to their peers'. In addition, genuine involvement of farmers is important. Farmers need to identify the research priorities: 'Growers need to identify comparisons that are relevant to their operation' and 'The important elements ... the ability of the farmer to choose the type of on-farm research that he or she would like to do'. Farmers also need to be involved in planning the research and fully understand the protocol: 'Another important detail is the grower's understanding of the plot protocol and the importance of proper planting and harvesting'.

Advisors identified the importance of their own role, as well as extension boards, and administrative support. One observed that it was a must to find 'Extension Educators who are willing to put in the necessary time'. Another identified the importance of time management and giving the project adequate priority: 'We all have to manage our time and work on priority issues. For us, this is a priority effort!' Supportive extension boards are vital: 'Supportive Extension Boards are a must ... they must see the benefits to the producers ... to know how the data will be shared'. Further, administrative recognition that the project is a time-intensive long-range investment for advisors is also crucial ' ... some administrators didn't see the big picture in the early days and I believe I was penalized for spending so much time with such a small group ... you have to invest time to get these things going and the pay-off isn't always immediate'.

Successful implementation and continuation can be compromised by rapid expansion, excessive time demand, and inadequate communication. One advisor commented:

> The larger the group gets, the harder it is to keep everyone focused on the goals of the group ... the interaction among farmers ... begins to fade. Also, as the group expands it becomes more difficult to have close oversight and you need to trust more people to do things correctly. The approach we took is very time consuming for the educators involved, so it has to be a priority for them, too.

> Too many research topics that do not yield information useful for increased profit can cause loss of interest:

'Another possible pitfall is a grower selects a comparison that does not have a significant impact on the profitability of their farming operation'.

Opportunities and obstacles to continued and greater success

Farmers responded with enthusiasm when asked to identify opportunities to make the research project more successful (Table 5). Opportunities were described as 'endless and unlimited'. Information needs driven by continued technological developments were recognized as an opportunity to continued success: ' ... with all the new technology in agriculture, there is no shortage of ideas'; 'Trying new ideas and using a group makes it easier to sort out new thought on a large scale' and 'Success is limited only by our imagination, so many things are out there and agriculture is changing so fast. We have to try and stay with or ahead'.

Farmers identified enhancement of farmer research skills, critical thinking and willingness to share information as opportunities for greater success (Table 5): '... building on what we have done', '... farmer ability to conduct research; willingness to share information' and 'Working with critical thinkers, growers and consultants is addictive and a formula for professional success'. The support of advisors was frequently mentioned as an opportunity to generate continued success. Opportunities to broaden the impact of farmer research were identified: 'set up a web-based clearinghouse to disseminate the research results and to promote farmer research throughout the State'. Greater farmer and consultant involvement in the project leadership was suggested.

Time and expenses required for good project implementation were the most frequently mentioned obstacles to continued success (Table 5): 'Costs involved to the farmer, mainly time and extra work' and 'Time and energy are our limiting factors'. However, respondents warned against seeking industry support for the research: 'Keep ... industry out of sponsoring, as they will taint the process'. Loss of interest in the research was another obstacle mentioned by several: 'Being content to live on the past successes'; and 'Farmers not seeing much value in what they are doing'.

Table 5. Opportunities and obstacles to continued and increased success of farmer research projects; number that named an opportunity or obstacle in response to open-ended questions.

	Farmers ($n = 44$)	Advisors ($n = 11$)
Possible opportunities to greater success		
The need for information	19	3
Farmer ability to conduct research	5	
Willingness to share information	3	2
Support of extension educators	2	3
Support of consultants		4
Enhanced critical thinking	3	1
Building on our accomplishments	3	
Cooperation in identifying good research topics	2	1
Research topic diversity		2
Statewide implementation of farmer research projects		2
Possible obstacles to continued success		
Insufficient time for implementation	16	4
Lack of funding	8	2
Loss of interest	4	2

Improving project implementation

Farmers were asked to identify the most time-consuming parts of their involvement in the project. Planting and harvesting the replicated trials, and ensuring proper application of the treatments, were most frequently cited as time consuming (Table 6) but recognized as needed and worthwhile investments: 'Time is just a part of it. Whether it is coming up with the ideas or implementing, it takes time'. Advisors also mentioned time constraints as limiting implementation. Norman et al.[12] also found this to be true for county agents in Kansas: 'Having far too many duties was by far the most important constraint' to more and better implementation of on-farm trials and demonstrations.

Two-thirds of the farmers who answered the question 'What could be done to simplify your involvement in the Project?' responded that no further simplification was needed: 'I'm not sure I want it simplified. I enjoy it or I wouldn't do it'. Two responses suggested simpler trials: 'Simpler plot designs' and 'Probably should have cut the size in half'. Two suggested that harvesting of trials can be eased with yield monitors: 'It has helped to use grain monitors on combine'. Following the protocol may ease trial implementation: 'Make sure I follow instructions correctly'. Most farmers (81%) answered 'just right' to the question 'Do you feel your level of involvement is too much, just right or too little?' Four replied 'too little' and one replied 'too much'.

The time requirement for conducting the research and satisfaction with the current farming practices were the

Table 6. Time-consuming factors in conducting farmer research identified by participating farmers; frequency of mention in response to an open-ended question, $n = 44$.

Time consuming factors	Frequency
Planting replicated trials	16
Harvesting replicated trials, collecting data	15
Applying the treatments	12
Paperwork, meetings, reporting	4
Planning trials	2

Table 7. The importance of reasons for farmers quitting or not becoming involved in the research project.

	Profitability Project ($n = 32$)	Quad County ($n = 12$)
Research required too much time	2.6[1]	2.7
Farmer was content with the practices currently used	2.4	2.3
Trials were difficult to implement	2.1	2.5
Farmer became less involved in crop production, e.g., retired	2.1	1.8
Farmer preferred to rely on other information sources	2.0	2.2
Farmer preferred not to share information	1.5	1.5

[1] Very important (3), less important (2), not important (1).

most important reasons for farmers quitting or not becoming involved (Table 7). Also important were farmer retirement and difficulty in implementing the trials. Lack of farmer willingness to share information with other farmers was not an important reason for non-involvement.

Guidelines for Implementing Farmer Research

The impact on farm profitability, the continuity, and the enthusiasm of participants indicate that both farmer research projects are successes and that similar efforts are needed throughout Nebraska (Tables 3 and 4). In this section, insights from farmer and advisor responses and authors' experiences are applied to develop guidelines for the implementation of farmer research projects, and to suggest means for improving existing farmer research projects.

Some of the guidelines may be applicable to farmer research for improving conventional cropping systems, alternative agriculture, and multi-functional agro-ecosystems (Table 8). Each of the guidelines presented in these tables is based on the survey results, with the exception of guideline #13 which is based on the authors' experiences. Additional guidelines are given for alternative agriculture and multi-functional agro-ecosystems.

Farmer research for alternative agriculture

Alternative agriculture is the largest growth sector in US agriculture and the organic industry alone grew at a rate of 24% for much of the 1990s[13]. Conventional and alternative systems may overlap significantly, in that conventional farmers often strive to increase bio-renewability or to diversify with specialty crops or products.

Private and public sector research has more frequently addressed conventional than alternative agricultural enterprises. Experience and information about a component of an alternative agriculture enterprise, e.g., a new crop under certain growing conditions, is relatively scarce compared to components of conventional agriculture. Therefore, alternative agriculture, compared to conventional cropping systems, may be able to achieve relatively large increases in profitability with a change of practices. Replicated, on-farm trials have a role here, as do less demanding research procedures. The farmer may need to do preliminary investigations to detect large effects before conducting more time-consuming replicated trials. Situations for discovery of information may be created, either in the field or through some form of simulation (e.g., crop growth models), which may yield adequate information to reject possible practices, plan other research, or possibly adopt a practice. Replicated trials conducted over time will be necessary to evaluate the success of fine-tuning the process.

In addition to the widely applicable guidelines in Table 8, the following guidelines for alternative agriculture were derived largely from the authors' reflections on their experiences and other information on involvement of farmers in research.

1. Consider the diversity of the participating farmers. Are enough interests shared to justify cooperation in farmer research? Are enough farmers interested to have specialized research groups, e.g., for organic farming or acreage owners?
2. Less-demanding research approaches in addition to replicated field trials may be valuable for screening alternative crops and practices providing sufficient information to reject some options. These might be 'discovery situations', where one or more practice is applied, or a new crop planted, to a part of or to the whole field, without replication, and maybe without a direct comparison, but with careful observation of crop performance.
3. Fine-tuning of production systems is likely to require that replicated trials are conducted to evaluate small effects with confidence.
4. Tours to visit the farms and research of participating farmers may be more important than with farmer research for conventional agriculture, for sharing of information, for participation in observation and interpretation of the observations, and for generating ideas for opportunities and information needs.

A limitation with alternative agriculture is that it often serves small niche markets for which supply can easily exceed demand. Entrepreneurs may, therefore, be reluctant to share information with other interested parties.

Farmer research for multi-functional agro-ecosystems

Diverse stakeholders have a growing interest in multi-functional agro-ecosystems where numerous land uses are concerns, e.g., crop and animal production, flood control and water quality protection, water and field recreation, tourism and aesthetics, and education. Diverse information is necessary to optimize resource management.

Table 8. Guidelines relevant for initiation and implementation of farmer research projects for conventional and alternative agriculture, and for multi-functional agro-ecosystems.

1. Introduce the idea of a farmer research project to likely farmer participants and county extension boards, with the assistance of an extension educator, consultant and farmers from an established farmer research project
2. Start small, with an adequate resource base, for a good start and later expansion. The ideal size in terms of participating farmers and geographic area was not addressed, but up to 40 farmers from a 4 or 5 county area has proven successful
3. Initial leadership by one or more extension educators who are committed to farmer research may be essential. Equally important is the involvement of farmers who are motivated to invest the time and other resources for successful implementation of research, able to promote the work with other farmers and, eventually, assume leadership roles in the project
4. Identify and prioritize research topics, and plan research, with individual farmers, but also in groups to stimulate innovation and cooperation among farmers
5. Initially, select topics of much interest and with a high probability of yielding profitable information, as such information will stimulate enthusiasm
6. Communicate clearly about the purpose and experimental processes of farmer research. Some basic introduction to experimental design and to statistical and economic analysis is needed, including the roles of replication and randomization, minimizing experimental error, repetition over years and/or farms, and probability in declaring an effect significant. This information may need to be repeated over time
7. Good implementation of trials is very important to success
8. Annual meetings of participants to discuss results are valuable to achieve full interpretation of the results, stimulate research ideas and disseminate information
9. Effectively disseminate research results beyond project participants, for example through a web site and with media reports
10. Enable interaction between existing farmer research projects
11. Involve, and provide feedback to, university research and extension specialists. Bring independent consultants, as well as agri-business personnel, into the process, but with clear understanding of their roles
12. Avoid financial support that might threaten the unbiased nature of the research
13. While not directly evaluated in this study, the role of tours, field days and informational meetings with a focus on farmer research may stimulate enthusiasm
14. Employ advanced technology as it becomes feasible, e.g., remote sensing, soil property mapping, yield mapping

Stakeholders and participants in such agro-ecosystems are likely to be diverse, including farmers, townspeople, natural resource managers, and possibly educators and/or developers/promoters of tourism and recreation. Information, experience, perspectives and interests of stakeholders in multi-functional watershed management are likely to vary considerably[2]. 'Opportunities for progress with an agro-ecosystem or multi-functional landscape approach may be enhanced with community involvement rather than limiting the process of opportunity and problem identification, information gathering or research, and decision making to the land managers.'[12] This will require a collective vision and focus on outcomes and a process of 'constant learning and adaptation to new insights and constantly changing conditions by all stakeholders'[14]. Knowledge sharing needs to be integrated with knowledge generation[5].

Most of the guidelines given above for conventional and alternative agriculture situations may apply to stakeholder research for improved multi-functional agro-ecosystems. Additional elements with involvement of a good representation of stakeholders may include: a vision statement; an inventory of resources; and prioritization of opportunities and needs.

Farmer research for multi-functional agro-ecosystem management may involve several approaches with more or less robust research methods, but with involvement of diverse stakeholders with a shared vision and a clear and coherent common agenda[15], including:

- landscape transects by groups of stakeholders to observe existing land uses and speculation on alternative uses for different purposes;
- study of existing components of the landscape (e.g., a segment of riparian area in a watershed) which may include use of remote sensing and Geographic Information Systems;
- creation of 'situations of discovery' in the field or using models;
- replicated field trials; and
- application of the triangulation principle, linking together multiple sources of information and methods[5,15].

Computer simulations and learning from other watersheds may be useful. The effects of some potential practices will occur too far into the future for replicated field trials to be feasible. Public-sector researchers may be challenged to move from approaches of producing information to apply in farming or agro-ecosystems, to discovery approaches of learning from farmers and their systems, coupled with collaboration in farmer research[16].

Conclusions

Farmers and advisors found that participation in a farmer research project is profitable and otherwise rewarding, despite considerable investment of their time at busy times of the year. Their responses indicated a need for similar research projects throughout the state of Nebraska, and

provided information that is directly applicable to the initiation and implementation of such projects for conventional crop production systems. This information was combined with information and experiences from other farmer research situations to develop guidelines to the implementation of farmer research for alternative agriculture systems and for multi-functional agro-ecosystems with diverse stakeholder involvement.

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Marketing locally produced foods: Consumer and farmer opinions in Washington County, Nebraska

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Abstract

Local food system potentials were studied in Washington County, Nebraska. As a departure from most studies of locally based systems, farmers were surveyed in addition to consumers for potential participation. Data about the current food system and opinions and preferences for local production, marketing, and purchasing of food were collected using self-administered mail questionnaires. The response rate was 35% for the farmer survey and 37% for the consumer survey. Results indicated that, on the farming side of the food system, conventional corn and soybean production and marketing predominated in Washington County, and farmer interest in producing for local markets was low. Consumers reported a high level of interest in purchasing food from farmers' markets, local grocery stores, local restaurants and directly from farms, and indicated a willingness to pay a price premium for local foods. They also reported that quality and taste were the most important factors in food purchase decisions, but environmentally friendly production and support for local farmers were also important. We conclude that there is tremendous potential for local marketing of farm products, but that there is a large gap between consumer demand and willingness of farmers to meet this demand. Further study of motivations and opinions of farmers is needed, in addition to determining production thresholds for the number of farms and farmers needed to meet local food demands.

Key words: consumer survey, farmer survey, direct marketing, local food systems, commodity crops

Introduction

Local food systems are emerging as a viable alternative to the production and marketing models used in the industrialized global food system. In addition to reducing food miles, stimulating local economies and providing farmers with alternative markets, these locally based systems can also be a model for agriculture at the rural–urban interface. The primary goal of this study was to examine farmer and consumer interest in locally grown foods in Washington County, Nebraska, which is located to the immediate north of Omaha. Population density in the county has increased, and urban expansion has resulted in fewer farms and increased rural residential development. The Washington County Comprehensive Plan that addresses land use was updated in 2004 to reflect changes in zoning, minimum lot size requirements for land sales and allowable dwelling units per section in response to increasing peri-urban development. This urbanization trend makes Washington County unique to Nebraska, and different from other rural areas in the US that are located farther from large cities.

Land-use changes observed in Washington County are similar to those at the national level. Farm trends in the USA reveal that farm size is increasing, while the number of farms is decreasing. Reduction of land in farms between 1997 and 2000 was 16,473,446 acres, or roughly 2% of the total land in farms[1]. In addition, farmers now represent only 1% of the total US population[2], while the urban population is at the same time increasing. Metropolitan residents currently account for 78% of the nation's population, while rural

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Table 1. Selected results of previous consumer studies.

Study	*N*	Study location and method	Preference for local foods
Adelaja et al. (1990)[5]	757	N. New Jersey: supermarket interviews	Positive
Brown (2003)[7]	544	SE Missouri: random sample mail survey	Positive
Eastwood et al. (1987)[11]	231	Knox County, Tennessee: random sample interviews	Weak (+ for 2 crops)
Gallons et al. (1997)[12]	1205	Delaware: random sample mail survey	Positive
Govindasamy et al. (1997)[8]	656	New Jersey: random sample mail survey	Weak
Kezis et al. (1984)[9]	2375	Maine, Delaware, West Virginia: random sample mail survey	Weak
Kezis et al. (1998)[13]	239	Orono, Maine: farmers' market interviews	Positive
Lockeretz (1986)[4]	666	E. Massachusetts: supermarket and farmers' market interviews	Weak
Patterson et al. (1999)[6]	571	Arizona: supermarket interviews	Positive
Ross et al. (1999)[14]	376	Maine: surveys in a workplace	Positive
Thomson and Kelvin (1996)[10]	1214	SE Pennsylvania: interviews at independent and chain supermarkets, farmers' markets	Weak
Wilkins et al. (1996)[16]	500	Northeastern US[1]: random sample telephone interviews	Positive
Zumwalt (2001)[15]	500	Nebraska, Iowa, Missouri, Wisconsin: random sample telephone interviews	Positive

[1] Connecticut, District of Columbia, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, West Virginia.

residents account for only 13% of the total[3]. This urbanization phenomenon poses challenges to farmers on the urban fringe, to rural communities that lose residents and infrastructure, and to planners who must mediate land-use conflicts. Food systems are also modified as prime agricultural land becomes prime land for residential development, turning food-producing topsoils into what developers and new residents consider aesthetic acreages and suburbs.

Despite these challenges, urbanization can have positive impacts on farmers and farming communities near urban centers. Lockeretz[4] suggested that the proximity of agriculture to cities should be turned into an advantage. Development pressures and land sales can result in smaller farms that can be integrated into the new 'edge' communities created when urban and rural areas meet. Higher-value crops can be produced on local farms and marketed directly to the broad consumer base in the nearby city and surrounding areas. Several studies have examined the potential of 'edge farms' because of the perceived benefits of local food systems. The literature has focused on consumer preferences and attitudes for locally grown foods, and on defining characteristics of consumers who purchase locally grown foods. In this study we surveyed both farmers and consumers in Washington County, Nebraska, to explore their opinions about producing and buying local food products in this peri-urban environment.

Previous studies

From the 1980s to the present, studies of local food systems have focused on consumers, and largely on preferences for fruits and vegetables, while few studies have dealt with meat and other food products in the same context. Methodologies have included interviews at supermarkets and farmers' markets, and random sample telephone and mail surveys conducted at community, county, state and regional levels. Results have been rather inconclusive, indicating both weak and strong consumer preferences for local foods. Attributes that are most important to consumers when purchasing foods have also been identified. Selected results of previous consumer studies that illustrate consumer preferences for local foods are shown in Table 1. At the time of this printing, several new studies of local food systems are in process.

Studies that examine consumer awareness and attitudes regarding state agriculture promotion programs provide one source of local food literature. Adelaja et al.[5] studied Jersey Fresh tomatoes, and found positive consumer preference and differentiation for the product as compared to tomatoes from other states and sources. Patterson et al.[6] studied the *Arizona Grown* promotion program and found that while consumers were largely unaware of the program, they indicated a preference for locally grown foods. Brown's[7] findings in southeastern Missouri were similar. Most consumers were not aware of the *AgriMissouri* promotion program, but still preferred locally grown foods. One reviewer thoughtfully pointed out that a lack of consumer awareness about state promotion programs provides a sad commentary on the effectiveness of such tax-funded activities in the public sector, a situation that should be corrected through publication of data from research, such as that presented here.

Several studies have concluded that consumer preference for locally grown foods is weak. Govindasamy et al.[8] found that consumers rated local production as an unimportant

produce characteristic. Kezis et al.[9] showed that produce origin was not as important to consumers as quality, appearance and price. Thomson and Kelvin[10] found that consumer preference for locally grown foods was generally weak, although three-quarters of respondents expressed some level of preference for local foods. Lockeretz[4] also found a generally weak preference for local foods, but found that consumers who shopped at farmers' markets valued the freshness of local produce. Lockeretz added that convenience was key, and may override consumer preference for local foods. Finally, Eastwood et al.[11] found that consumers in Knox County, Tennessee preferred locally grown tomatoes and peaches, but origin of apples, broccoli and cabbages was not important.

Conversely, several studies have shown positive consumer preference for locally grown foods. Studies of consumers at farmers' markets and direct markets have shown that those consumers value local foods. The Gallons et al.[12] study of consumers who purchased directly from Delaware farmers showed that consumers valued the local produce selection as well as the local origin of the produce, and they wanted to support local farmers. Kezis et al.[13] found that consumers at the Orono, Maine farmers' market were loyal, weekly shoppers who valued the high quality of local produce. The authors further found that consumers were willing to pay a premium for local foods. Ross et al.[14] found that consumers who were provided locally grown produce at their workplace came to prefer it over conventional produce. These results are drawn from samples of consumers already participating in locally based food markets.

Surveys using a random sample of consumers have also yielded positive results for local food preference. Zumwalt's[15] study of four Midwestern states found that the vast majority of consumers (99%) reported having purchased locally grown or produced foods at some time in the past, and that preferences for locally grown foods were positive. Additionally, high levels of interest were reported for purchasing local foods from grocery stores, farmers' markets, local farmers (direct), and restaurants and cafeterias. Finally, Wilkins et al.[16] reported consumer support for locally grown produce in the northeastern US, and found that consumers were willing to pay premiums for local foods.

The focus in the local food system literature is on consumer attitudes and preferences, especially in regions of the USA where farmers are already growing for local, direct markets. While focus on the consumer is an important component of food system research, a concurrent focus on farmers is also needed in order to gauge real potential for local food systems. This may be particularly true for studies in areas of the USA with lower population densities, where local food systems are not well developed and the farming system is dominated by commodity crop production.

In light of previous studies of consumer preference and participation in local food systems and the lack of farmer inclusion in these studies, specific objectives of the current study were to: (1) examine the current food system in Washington County, Nebraska; (2) determine food preferences of consumers in the market place; (3) examine consumer interest in purchasing foods from local markets; (4) determine whether or not consumers were willing to pay a price premium for locally grown foods; and (5) examine farmer interest in producing for local markets. The inclusion of farmers in this study was unique and expands the local food system literature.

Methods

Consumers and farmers were studied as two distinct populations using two independent survey instruments. In both cases, self-administered mail surveys were sent in September of 2003 following a modified version of Dillman's[17] Total Design Method. First, a personalized, pre-notification letter communicating the nature of the study was sent to people in both samples. Next, a personalized cover letter including informed consent documentation, a questionnaire and a return business envelope was mailed. One week later, a follow-up postcard was sent to the entire sample to serve as a note of gratitude to those who had already responded, as well as a reminder to those who had not.

The consumer sample was stratified proportionately so that the sample distribution would be the same as the population. Washington County has five towns with populations of at least 300 (Blair, Arlington, Ft. Calhoun, Kennard and Herman), and a substantial rural population[18]. The number of surveys administered in each geographic region (five towns and rural) was determined by multiplying each region's percentage of the total population by 600, which was the number determined for the starting sample based on Salant and Dillman[19]. Systematic sampling with a random start was used for drawing the consumer sample from telephone books and the Washington County TAM/PLAT directory of rural residents. The initial starting sample was adjusted to 567 after incorrect addresses were removed, and a total of 207 completed surveys were returned from the consumer sample for a 37% response rate.

The farmer sample was drawn from a list obtained from the Washington County Farm Service Agency (WCFSA). Questionnaires were sent to all 507 farmers registered with the WCFSA. The adjusted starting sample was 480, and a total of 168 competed surveys was returned for a 35% response rate.

In order to achieve useful and consistent interpretation of terms, the following statement was given prior to questions about local foods in both survey instruments, 'For the purpose of the following questions, *locally grown or produced* means that the food was grown on a local family farm or made by a local company (Local = Washington County or nearby areas)'.

Results

Characteristics of those who responded to the survey compared to data on the population collected in the US

Table 2. Characteristics of survey respondents compared to Washington County residents and Washington County Farmers.

Consumers (n = 207)		
Characteristic	**Respondents**	**2000 US Census**
Gender		
Male	51%	50%
Female	49%	50%
With children <19		
Yes	27%	26%
No	73%	74%
Education level		
< High school	4%	11%
High school graduate	29%	36%
Some college	26%	24%
College degree (2 years)	5%	7%
College degree (4 years)	25%	16%
Postgraduate	11%	7%
Median income ($US)	40,000–49,999	48,500
Farmers (n = 168)		
Characteristic	**Respondents**	**2002 Census of Agriculture**
Farm size (acres)		
1–9	7%	6%
10–49	19%	25%
50–179	30%	24%
180–499	31%	22%
500–999	9%	15%
1000+	4%	7%
Age (mean)	56	54

Census[20] and the Census of Agriculture[21] are given in Table 2. Consumers were representative of the population in gender distribution, children living in the home, and median income. Consumers who responded to this survey had higher levels of education than the population, so results cannot be generalized to people with an average or lower educational level. Farmers were representative of the population in average age and farm size. Other data on Washington County farmers were not available for comparison.

The current state of the Washington County food system: production and marketing characteristics

Farmers were asked about their farm holdings for five different categories: acres owned, acres farmed, cropland acres, contract acres and pasture acres. Estimates of changes in farm size from 5 years ago to the present, and a projection for changes over the next 5 years were assessed by asking respondents to report their recent farming history as well as anticipated changes in the future, according to the method of Grieshop and Raj[22]. For all farm categories, current acreage increased from 5 years in the past, and farmers predicted further increases in the future. Table 3 shows the attendant mean statistics. Most farmers (66.9%) had rented farmland; landlords were family (33.3%), non-family (37.8%), and both family and non-family (28.8%).

Table 3. Mean acres for the current year (2003), 5 years in the past, and projections for 5 years in the future (n = 168).

How many total acres.....	Total number of acres 5 years ago	Total number of acres this year	Total number of acres 5 years in the future (projected)
Do you own?	242.1	261.0	297.8
Do you farm? (both rented and owned acres)	590.2	627.2	728.9
Cropland?	541.0	569.6	665.5
Crops grown on contract? (i.e., seed, specialty grains)	12.1	21.8	30.4
Pasture?	27.4	28.2	30.8

Farmers were also asked about the crops and livestock produced on their farms. For crops, an open-ended question was used so that farmers could list the crops they grew. For livestock, an initial 'yes' or 'no' question was asked to determine whether or not farmers had livestock on their farms. A more in-depth question about five types of livestock followed. Most farmers (70.9%) in Washington County grew corn and soybeans in rotation, or corn, soybeans and alfalfa (Table 4). Just over half of the farmers (50.6%) reported having livestock on their farms, with beef cattle as the most common livestock, and dairy cows as the least common. Many farmers reported having had cattle, hogs and chickens in the past (Table 5). Crops and other farm products were largely marketed through the local grain elevator or wholesaler (83.2%) and through an industry operation (70.3%). Many farmers used more than one of these markets, as shown in Table 6.

Table 4. Crops grown in rotation as reported by farmers (n = 165).

Crops grown in rotation	Number of farmers	Percentage
Corn and soybeans	66	40.0
Corn, soybeans and alfalfa	51	30.9
None	17	10.3
Corn, soybeans, alfalfa and oats	10	6.1
Corn, soybeans, alfalfa and wheat	4	2.4
Other: trees, grapes, prairie hay, milo, vegetables, perennials and other rotations	17 (total of 'other')	Under 2% (each rotation)

Table 5. Farmers who currently have, do not have, and used to have livestock, and mean numbers for each type ($n = 168$).

Livestock	Currently have	Mean number of animals	Do not have	Used to have
Dairy cows	7.0%	112.0	82.0%	10.9%
Beef cattle	36.9%	141.8	39.0%	24.1%
Hogs	17.4%	800.8	45.7%	37.0%
Broilers (chickens)	5.3%	123.9	80.5%	14.3%
Layers (chickens)	6.7%	64.8	78.4%	14.9%
Sheep, horses, ducks, goats, guineas, ostrich, llamas	Under 2% (each type)			

In addition to farm data collected from the survey, information about food markets was collected from the Washington County Pilot Tribune and Enterprise website[23]. In 2004 there were 31 restaurants, including bar and grill establishments, in the county. Eight fast food restaurants were included in this total count. The county housed five grocery stores spread among three towns; Blair, Arlington and Ft. Calhoun. Blair also had a farmers' market with 25–30 vendors that was open twice weekly during the spring and summer. Most vendors were hobbyists, vegetable growers or retired farmers (J. Peterson, 2003, personal interview, Washington County Extension Office, Blair, Nebraska). We recognize that Omaha also has a viable farmers' market through the growing season, but it is not clear from the results if this option for both farmers and consumers was a factor that influenced results of the study.

Consumer food preferences and interest in local foods

Consumers were asked to rate the importance of 12 attributes of food brands or products using the following scale: Not Important = 1, 2; Somewhat Important = 3, 4, 5; Very Important = 6, 7, 8; and Extremely Important = 9, 10. Results shown in Table 7 reveal that quality, taste, nutrition and price were most important to consumers in Washington County. Products that were produced in an environmentally friendly manner and support local family farms were also very important. Products that were produced locally or in Nebraska, or carry a local store brand were somewhat important. All-natural and organic foods were least important to consumers, although they were still ranked as being somewhat important.

Table 6. Farmers who used various markets for their crops and other farm products ($n = 168$).

Markets	Percent that use this market
Local grain elevator/wholesaler	83.2
Industry operation (i.e., Cargill)	70.3
Contract	32.7
Direct sales to consumers	24.2
Farmers' market	4.1
Direct sales to a local grocery store	1.4

Consumers drove various distances to purchase their household groceries. Some drove less than 5 miles ($n = 70$, 35.2%), some drove 5–10 miles ($n = 60$, 30.2%) and some drove 10–20 miles ($n = 64$, 32.2%). Very few ($n = 5$, 2.5%) drove more than 20 miles to purchase groceries. Most consumers (63%) reported that they had purchased some locally grown foods in the past. Most had purchased fruits (48%) and vegetables (58%) locally, while less than half had purchased eggs, beef, pork, chicken or dairy products from a local market. The majority of consumers reported that they had and/or would purchase all of the listed food items from a local source. No respondents indicated that they would not buy any foods locally, and very few indicated that they would not purchase specific food items locally. Table 8 shows the percentage of consumer participation in purchasing each of these food items.

Consumers were also asked about their willingness to pay a price premium for local foods. Table 9 shows that most consumers (58%) were willing to pay an equal price for food grown locally as compared to foods grown elsewhere. Thirty-four percent of consumers were willing to pay a 10% premium for local foods, 1% would pay a 25% premium, and 1% would pay more than a 25% premium.

In order to gauge potential consumer participation in specific local marketing channels, data were collected on interest in using four local sources: direct sales from a farm, farmers' markets, local grocery stores and local restaurants. Table 10 shows that less than 10% of consumers reported that they were not interested in any of the four markets, while the highest percentage of consumers were 'Very Interested' in all four markets. Farmers were also asked about their interest in using the same four markets as outlets for selling crops and other farm products. Table 11 shows that the highest percentage of farmers reported that they were 'Not Interested' in any of the four markets, and less than 10% of farmers were 'Extremely Interested'.

Discussion

Commodity grain production on farms that are increasing in size is the predominant form of agriculture in Washington County. A local food system has not been developed in the area, and very few farms are designed for production of food crops instead of feed and commodity grain crops. Despite these realities, the present study indicated that consumers in the area were interested in supporting a local system.

Consumer preference for locally grown foods

Consumer preference results from this study supported previous findings that quality and taste were among the

Table 7. Importance of food brand or product characteristics reported by consumers in Washington County ($n = 207$).

Food brand or product characteristic	Mean rating based on a 10-point scale	Percent that rate item as 'Very to Extremely Important'	Rank based on mean
Product's quality	8.56	98.5	1
Product's taste	8.52	98.0	2
Nutritious and healthy	8.27	93.8	3
Product's price	8.15	90.7	4
Product is environmentally friendly	6.76	72.4	5
Purchase supports a local family farm	6.07	55.7	6
Nebraska grown	5.73	52.6	7
Locally grown/produced	5.63	51.8	8
Made by a small local company	5.30	44.6	9
Local store brand of label	5.23	45.9	10
All-natural food	4.61	32.6	11
Organic	4.20	27.7	12

most important factors for consumers when purchasing food products. However, consumers in Washington County rated the importance of their purchase being produced in an environmentally friendly manner and supporting a local family farm higher than previous results have indicated. Brown[7] found that household location influenced consumer preference for local products in southeastern Missouri. Rural residents were more willing than urban residents to seek out local products. This study of Washington County, Nebraska may concur with this finding, as the entire county is arguably rural. A parallel study of nearby urban residents in Omaha would need to be done to confirm this hypothesis.

Most consumers reported having purchased locally grown foods in the past. Blair, the county seat, had a farmers' market in the spring and summer, and roadside stands have also been used, although not on a regular basis and not for regular business (J. Peterson, 2003, personal interview, Washington County Extension Office, Blair, Nebraska). Even though local markets are limited, consumers indicated that they were willing to purchase local foods. This finding, coupled with the importance consumers placed on food purchases supporting local farmers, points to significant consumer interest in a local food system in Washington County.

Table 8. Consumers who *have* purchased local foods, who *have and would* purchase local foods, and who *would not* purchase local foods ($n = 207$).

	Have purchased locally	Have and would purchase locally	Would not purchase locally
Any local foods	63%	96%	0%
Fruits	48%	97%	1%
Vegetables	58%	98%	1%
Eggs	34%	89%	6%
Beef	37%	94%	4%
Pork	30%	92%	5%
Chicken	28%	92%	5%
Dairy (milk, cheese)	18%	82%	11%

Price premiums for locally grown foods

Findings in this study that consumers were willing to pay a price premium for locally grown foods supported results in other studies. Eastwood et al.[11] reported that 50% of consumers in Knox County, Tennessee would pay more for local tomatoes. Wilkins et al.[16] reported that 80% of respondents in the northeastern United States were willing to pay more for local produce. Kezis et al.[13] found that 72% of respondents in their study of Maine consumers were willing to pay a 17% premium for local foods. Brown[7] found that 58% of respondents in Missouri would pay prices for local foods equal to other foods, that 16% would pay a 5% premium, and that 5% would pay a 10% premium. These findings suggest that consumers are willing to turn their attitudes into behavior by supporting local foods through price premiums. However, Lockeretz[4] and Ross et al.[14] warned that even a strong preference for local foods may not be translated into action unless a convenient market exists. Because the local system in Washington County is not well developed, this lack of convenience may present a challenge to consumers interested in local foods. Additionally, the willingness to pay a 10% price premium reported in the present study is likely not high enough to support local farmers, much less to entice them to change their production systems to meet market demand.

Table 9. Price premiums consumers were willing to pay for locally grown or produced foods compared to typical prices for similar items ($n = 207$).

	Percentage of consumers
Less than typical price	6
Equal to the typical price	58
10% above typical price	34
25% above typical price	1
Greater than 25% above typical price	1

Table 10. Consumer interest in purchasing locally grown foods from various local markets ($n = 207$).

Market	Not interested	Somewhat interested	Unsure	Very interested	Extremely interested
Direct from a local farmer	5.7%	27.6%	16.7%	39.1%[1]	10.9%
Farmers' markets	2.5%	21.4%	12.4%	50.7%[1]	12.9%
From a local grocery store	2.6%	16.8%	10.7%	55.1%[1]	14.8%
From a local restaurant	7.2%	18.6%	23.2%	44.3%[1]	6.7%

[1] Highest percentage.

Table 11. Farmer interest in using various local markets for selling crops and other farm products ($n = 168$).

Market	Not interested	Somewhat interested	Unsure	Very interested	Extremely interested
Direct sales to consumers	47.8%[1]	23.6%	9.9%	11.2%	7.5%
Farmers' markets	65.2%[1]	12.4%	16.1%	3.7%	2.5%
Direct sales to a local grocery store	67.7%[1]	7.5%	16.1%	4.3%	4.3%
Direct sales to a local restaurant	71.4%[1]	7.5%	13.0%	5.0%	3.1%

[1] Highest percentage.

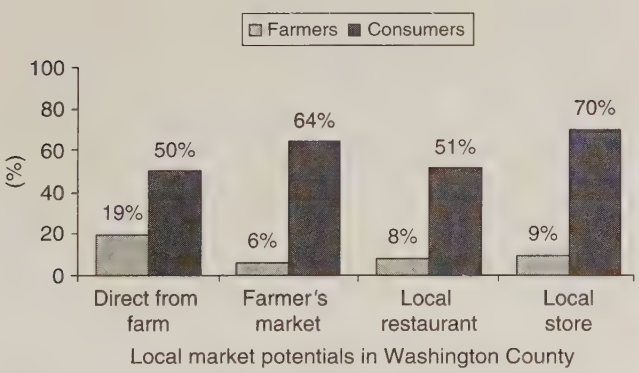

Figure 1. Local market potentials in Washington County. Farmers and consumers who were very to extremely interested in using local food markets. 'Farmers' bars represent the percentage of farmers ($n = 168$) who were very to extremely interested in using local markets for selling their crops and farm products. 'Consumers' bars represent the percentage of consumers ($n = 207$) who were very to extremely interested in using local markets for purchasing locally grown or produced foods.

The connection: consumer and farmer interest in local markets

The examination of consumer interest in local markets in conjunction with farmer interest about the same markets revealed interesting results. After consumer preference and willingness to pay premiums were established, it was important to determine where consumers wanted to purchase local foods. The findings of the present study indicated that consumers were interested in buying local foods directly from farmers, from farmers' markets, from local grocery stores and from local restaurants. These results signal a clear market potential for local products.

However, farmers were not as interested in using these markets for selling crops and farm products. Figure 1 illustrates the differences reported by consumers and farmers. For each type of market, consumers indicated much higher levels of interest in using the source to buy food than farmers indicated to use the source to market and sell food. These data can be interpreted in two ways. First, this gap between farmer and consumer interest might highlight an important problem on the production side of the local food system. It may be the case that the number of farmers both interested in and able to meet the market potential and demand is a limiting factor in developing local systems. On the other hand, while it seems that farmer interest in this study was low, it is important to determine how many farms and farmers are needed to satisfy consumer demand in a given area. It is possible that the level of interest expressed by farmers in the present study is adequate for the current level of consumer interest. Further study of productive capacities of local food sheds is needed to determine points of market saturation.

Conclusions

Local food systems and direct marketing can increase the profits that farmers receive, and can help to mediate the pains associated with urban expansion. By marketing food products to urban and suburban neighbors, farmers can potentially stay in business, while supporting the local economy and keeping farmland in production. However, results from this and other studies indicate relevant challenges to the locally based model. Farmers that produce commodity grain crops are highly invested in this conventional system through equipment and increased acreage costs, and often through tradition and know-how. The changes required to service local food markets involve not only dramatic changes in the production system, but potentially a paradigm shift as well. Government programs support large-scale commodity production, but offer no incentive for farmers to grow food to feed people locally.

Given these realities, the low level of farmer interest in producing for local markets found in the present study is not surprising.

Studies of local food system potentials have focused on consumers from the 1980s to the present. Results, while not fully consistent, have generally shown consumer interest in buying local foods and even paying a price premium. But the inclusion of farmers in these studies is vital for understanding the situations and perspectives of local farmers, so that results reflect real opportunities and challenges. There are structural and philosophical impediments to local food systems that need further examination. Additionally, research should work to establish farm thresholds for the number of farms needed to satisfy potential local markets without reaching saturation. Location-specific food shed studies can provide useful information for communities such as Washington County that may consider establishing a local food system.

This study and its findings should be viewed as a preliminary examination of the potentials for local food systems in areas where conventional commodity grain production dominates. Further questions need to be asked. How would farmer interest in producing for local markets change if current farm programs were significantly reduced, or if financial incentives for supplying local systems were introduced? What would happen if states such as Nebraska offered financial incentives such as decreased sales tax to both farmers and consumers for supporting local food systems? Would beginning farmer programs especially geared for small farms that supplied food locally increase interest in local food systems? Following from these questions, in addition to studying consumers and farmers, agricultural policy needs to be included in the examination and analysis of local food system potentials.

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The adoption and impact of management intensive rotational grazing (MIRG) on Connecticut dairy farms

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Abstract

Management intensive rotational grazing (MIRG) has garnered a great deal of interest in recent years as a method for returning profitability to Northeastern dairy farms. This work uses a random sample of Connecticut dairy farmers to estimate a binary choice adoption model and then cost, productivity, and profit functions that control for the adoption choice. MIRG adopters are shown to be more educated and have less rented agricultural land (a proxy for lack of access to land within a short distance of the barn). MIRG adoption had no significant effects on costs and productivity, nor did it lower profits, per cow. Evidence was found, however, to suggest that full adopters of the technology had more profitable farms than partial adopters. These results also show the importance of controlling for the different characteristics of adopters when evaluating the returns to animal grazing.

Key words: Management intensive rotational grazing, dairy, technology adoption, economics, productivity

Introduction

A centuries-old technique, the management of cow grazing, has garnered a great deal of interest in recent years as a method for returning profitability to Northeastern dairy farms. Management intensive rotational grazing (MIRG) incorporates recent advances in the understanding of plant and animal production into an old technology, the management of cow grazing. While most new technologies seek to increase productivity as a means of increasing profits, this one seeks to lower costs per unit of output. Research has shown that MIRG can decrease milk production costs, though generally at the expense of milk production, suggesting that the overall profitability is uncertain.

To date, research on MIRG has concentrated on the productivity and profitability while ignoring the adoption decision farmers make. In addition, many of the current studies have used selected non-representative samples of farmers and have not been able to determine the overall profitability of a farm using MIRG for a full sample of the dairy farm population. This work seeks to go beyond the earlier work by using a random sample of Connecticut dairy farmers to investigate who adopts MIRG and who receives higher farm profits from it. The work estimates a probit binary choice adoption model and then cost, productivity, and profit functions that use predicted values from the adoption choice model to control for the possibility that adoption and cost, productivity, and profit are jointly determined. In other words, adoption decisions may be endogenous to other farm outcomes: the characteristics that influence farmers' decisions to adopt MIRG may also influence cost, productivity, and profit outcomes. In addition, this work estimates the economic returns to different rates of grazing rotations.

A summary of the current literature on grazing sets the context for this work. The econometric estimation methodology is discussed and data description provided. Finally, estimation results of an adoption equation, and cost, production, and profitability equations as well as policy conclusions are presented.

Literature on MIRG

A growing body of literature has investigated the role modern rotational grazing techniques can play as an alternative to confinement feeding systems. A number of recent simulation studies have demonstrated that, from a technical standpoint, grazing can be at least as profitable, if not more so, than conventional confinement systems. For example, Elbehri and Ford[1] did a Monte-Carlo simulation of a Pennsylvania

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Holstein dairy farm and found lower costs and increased profits from intensive grazing relative to a confinement system. Frank et al.[2] simulated a whole-farm economic model for different grazing scenarios on typical southwest Wisconsin dairy farms and showed increased profits with grazing.

Other recent studies have used a case study methodology to get a detailed picture of the potential profitability on actual farms. For example, Pillsbury and Burns[3] looked at Voisin grazing management adoption and daily rotational grazing in a longitudinal study of one Vermont farm and showed lower costs with daily rotation compared to confined feeding, and increased benefits with daily rotation compared to extensive grazing. Emmick and Toomer[4] compared the costs before and after intensive pasture adoption on 15 farms in New York, to find a reduction of production costs of $153 per cow. Bower-Spence[5] compared profits from confinement and intensive grazing operation on a single Pennsylvania farm that switched from one to another, and found increased profits for grazing.

With an increase in the number of farms using MIRG in many upper-Midwest and Northeastern states, a number of studies have reported the results of on-farm surveys of farmers adopting grazing. Ford and Hanson[6] summarized two Pennsylvania studies showing the characteristics of dairy grazier practices that lower feed costs and generate higher profits for grazing farms compared to non-grazers. Jackson-Smith et al.[7] used two representative surveys to characterize grazing management practices and to analyze economic performance of MIRG users. They showed lower costs for grazers compared to confinement operations, but did not report profitability estimations. A sample of northeastern Pennsylvanian farms showed decreased profits under grazing[8]. Hanson et al.[9] combined New York and Pennsylvania dairy farm samples for an empirical analysis that showed lower profit and increased production for extensive grazing and higher profit and increased production for moderately intensive grazing than that for farms that did not graze. Winsten et al.[10] found decreased productivity, costs, and profits for either extensive or intensive (>75% forage from daily rotation) grazers compared to confinement systems in a sample of Northeastern (PA and VT) dairy farms. However, once other factors have been controlled for, they found that profitability on grazing farms was not significantly different from that of confinement operations.

This study follows the spirit of the on-farm survey studies. While most of these studies have collected data from a large number of farmers, it is unclear in all but those by Jackson-Smith et al.[7], whether the sample is truly representative of all farmers or just a select few. In addition, while all of these studies have investigated costs and profitability, they did not control for the adoption choices being jointly determined with costs, productivity, and profits. Both the select sample and ignoring that adoption is potentially endogenous to other outcomes will bias the results. In particular, farmers who are most likely to graze should also be those for whom grazing is most likely to increase total farm profits. When comparing profits, one might then overstate the returns to grazing by ignoring this joint determination or endogeneity. The next section details the econometric procedure used to account for the joint determination of grazing choices.

Methodology

Using survey data from Connecticut, a model similar to Stefanides and Tauer's[11] recombinant bovine somatotropin (rBST) model is used to estimate the effect of MIRG on profits of Connecticut dairy farms. This methodology involves a two-step process of estimating the probability that a farmer is a grazier and then using that probability in an estimate of the cost, production, and profit functions. This methodology differs from that used in most of the previous studies on MIRG listed above, in that estimates of costs, production, and profits are a function of the farmers' adoption decision. Modeling the joint determination of adoption allows us to control for the fact that the sample of MIRG users is not representative of all farms.

Since the joint determination of adoption is the same for costs, productivity, and profits, we illustrate it only for profits. Assume that profit (Y) is a linear function of explanatory variables (X) and an MIRG dummy variable (R), so the linear regression equation is

$$Y = \beta' X + \delta R + e, \tag{1}$$

where e is a normal random disturbance and R is a 0 or 1 dummy variable for the use of MIRG ($R = 1$ if MIRG is adopted and $R = 0$ otherwise). Note that a farmer's decision to adopt is dependent on many of the same characteristics of farm and farm operator that would also influence profits. Thus, R should be treated as an endogenous, jointly determined variable. An index function (probit) model will be used to estimate the adoption equation:

$$R^* = \gamma' Z + u, \tag{2}$$

where R^* is an unobservable index variable, $\gamma' Z$ is called the index function and Z represents explanatory variables, and u is an error term such that $u \sim N(0,1)$. In this case, the observable dummy variable is:

$$R = 1 \quad \text{if } R^* > 0 \quad \text{(adopt MIRG)},$$
$$R = 0 \quad \text{if } R^* \leq 0 \quad \text{(not adopt MIRG)}.$$

From equations (1) and (2), the expected profit, Y, can be obtained from

$$\begin{aligned} E[Y] &= E[Y|R=1]^*\text{prob}(R=1) \\ &\quad + E[Y|R=0]^*\text{prob}(R=0) \end{aligned} \tag{3A}$$

$$= \beta' X + \delta \Phi(\gamma' Z), \tag{3B}$$

where Φ is a cumulative standard normal function. Thus, $\Phi(\gamma' Z)$ serves as the instrumental variable for R in equation (1) to avoid the biases of estimators. Using this framework, the parameters of both the adoption decision and the profit equation are obtained.

Table 1. Rotation intensity categories.

Category	Number of rotations per month (x)	% of survey in category
Method 1: six categories		
7	$x=0$	61.3
6	$0<x>4$	17.7
5	$x=4$	2.4
4	$4<x>7.5$	3.2
3	$10<x>15$	5.7
2	$x=30$	5.7
1	$x=60$	4.0
Method 2: three categories		
None	$x=0$	61.3
Slow	$0<x\leqslant 4$	20.1
Fast	$x>4$	18.6

In order for $\Phi(\gamma'Z)$ to serve as a valid instrument, we need an exclusion criterion to identify the parameters: some variables that describe the decision to be a grazier do not influence either costs, productivity, or profits (Greene[12], p. 295). The fragmentation of agricultural land in Connecticut and the inability to move cows along roads give us such a criterion. Only farms with suitable pasture within cow walking distance of their barns can engage in grazing to a serious extent. But this distance between the land base and the barn should have no bearing on the costs, productivity, or profits of farms in general. Thus a reasonable variable to include in Z but exclude from X would be the one that proxies this distance from the barn to the land base. (Note that in the increasingly suburban environment of Connecticut, the key determinant of getting cows to a pasture is not how far they can walk or how long it takes, but the amount of traffic along the roads that the cows would inevitably have to cross.)

This work uses this framework to estimate cost, production, and profitability functions with a jointly determined adoption decision. First the adoption equation is estimated, then the predicted probability of adopting is added as a variable in successive estimations of production, cost, and profit equations. [Due to significant heteroskedasticity of the error terms, the production, cost, and profit equations were estimated using standard errors corrected with the Huber–White procedure (Greene[12], p. 505). Note that, as suggested by a reviewer, one could estimate the production, cost, and profit equations as a system of equations using, for example, the seemingly unrelated regression (SUR) framework. Such a framework would be appropriate if the equations had correlated error terms, but estimates of an SUR model with our data showed an insignificant correlation. The Bruesch–Pagan χ^2 test (with three degrees of freedom) of independence of the residuals among the regressed equations = 0.661 with Pr = 0.8822, so we fail to reject the null hypothesis that the residuals of the equations are independent.] In addition, a profitability equation is estimated parameterizing the grazing decision by using the length of grazing rotation as a variable. This last equation is intended to provide some evidence on the profitability of different intensities of rotational grazing.

Table 2. Farm characteristics.

Averages	MIRG users 18.3%	MIRG non-users 81.7%
Profit per cow	\$458.75	\$369.01
Production (lb) per cow	17,636	20,190
Costs per cow	\$2,340.83	\$2,737.25
Number of cows**	69.8	144.7
Owner's age (years)	47.9	52.4
Owner's education* (years)	14.0	12.9
Technology use index	6.47	7.49
Use freestall housing for the milking herd*	56.3%	76.9%

Significance levels: * 10%, ** 5%.

The Data

In 1999, the University of Connecticut conducted a survey of dairy farmers in the state. The survey's objectives were to assess the competitiveness of Connecticut dairy farms and the adoption of new technologies, including MIRG. All 245 Connecticut dairy farms received a survey, and 124 returned useable information on their dairy farms, representing a 51% response rate. (An estimate of the sample inclusion probability using a list of all Connecticut dairy farmers and their size, productivity, and location, found no significant parameters.) Connecticut dairy farms are relatively small-scale businesses, with more than 60% of farms having fewer than 100 milking cows. The farmers are on average well-educated, productive farmers, with a rolling herd average of 19,800 lb per cow.

In order to have a definition of being a grazier that is consistent with both practice and the literature, we use one developed by Jackson-Smith et al.[7]. A farm is designated as using management intensive rotational grazing if they:

(1) rely on pasture for at least part of the forage ration of any milking cows,
(2) usually move grazing cows to a new paddock at least once a week, and
(3) make pasture the primary source of total feed for milking cows during the grazing season.

Using this definition 18% of the sampled farmers were classified as being graziers. A further 20% graze their milking cows to some extent, see Table 1.

The general characteristics and technology differences between MIRG users and non-users are shown in Table 2. Between MIRG adopters and non-adopters, it shows that MIRG users have higher profits on lower productivity and lower costs. These are not significantly different at commonly used statistical significance levels (e.g., 1%, 5%, or 10%). Only the number of cows on the farm is statistically different at a 5% level, with MIRG users having on average half the number of cows per farm as

non-grazers. MIRG users appear to be better educated, with an average level of 2 yr of college as compared to 1 yr for non-grazers, although one needs to run the regressions shown below in order to determine whether this is merely an artefact of MIRG users also being younger. MIRG users also are less likely to have freestall housing, although the levels of use of productivity-increasing technologies are not statistically different between MIRG users and non-grazers.

Estimations

Following equation (2) and the literature review, the MIRG adoption equation is hypothesized to have the following form

$$\begin{aligned}\text{pr(MIRG)} = {} & B_0 + B_1 \text{ owned land} + B_2 \text{ rented land} \\ & + B_3 \text{ owner's age} + B_4 \text{ owner's education} \\ & + B_5 \text{ no. of hires} + B_6 \text{ years farmed.}\end{aligned} \tag{4}$$

As with the adoption of other dairy technologies described in the literature[11,13], MIRG adoption is expected to be decreasing in age and increasing in education. The adoption equation uses the acres of owned land, rented land, and how long the family has farmed the land as proxies for how easily a farmer could start grazing. We expect that farms with more owned land, who have farmed the same land for more years, would have more land near their barns and thus would be more likely to graze. We expect the opposite effect with rental land. Since the literature reports many grazers adopting the practice to make use of family labor, adoption probabilities are expected to be decreasing in the number of hired workers.

The production per cow estimation is shown below as

$$\begin{aligned}\text{Production/cow} = {} & C_0 + C_1 \text{ farm size (cows)} \\ & + C_2 \text{ owner's age} \\ & + C_3 \text{ owner's education} \\ & + C_4 \text{ technology index} \\ & + C_5 \text{ pr(MIRG).}\end{aligned} \tag{5}$$

It has variables measuring farm size (the number of cows including dry cows) to control for returns to scale, two proxies for management ability (owner's age and years of formal education, which are weighted by percent ownership in the case of multiple owners), and a general technology measure (the number of the 11 key productivity-increasing technologies used on the farm). For the estimations in this study, milk production is defined as average milk production per cow. A last variable, R^* from equation (1), measures the MIRG adoption probability. The literature review in the previous section provides conflicting evidence on whether grazing will increase or decrease production per cow. We hypothesize that production per cow will increase with farm size, management ability proxies, and with technology use.

Typically, farm costs and profits are estimated as a function of output prices, production levels, and fixed factors[14]. Differences in milk prices within the Connecticut market, where a single buyer, Agrimark, purchases most of the milk, will primarily be between time periods rather than between farms. In a single year of cross-section data, farmers will face very similar input and output prices, and the primary differences between costs and profits across farms can be described as functions of fixed factors, technology adoption, and production choices. The profit and cost equations also include a variable that captures the percent of farm revenues accounted for by milk sales, in order to control for differences between farms which may have other profitable/costly activities and a possible correlation between those activities and being a grazier.

Costs are calculated as total farm expenses per cow, including all operating costs and depreciation costs claimed on farmers' taxes; while profits are defined on a per cow basis as 1998 total farm receipts (including milk, livestock, crop sales, and all other farm receipts) minus total farm expenses. Note that the cost and profit measures ignore potential changes in inventory, but an analysis of the data on herd size changes on these farms shows no significant relationship between cow inventory changes and the 1998 cost and profit data, suggesting that inventory changes do not cause an omitted variable bias to our results. The cost equation estimation is similar to the production equation with the addition of two variables: production per cow and percent of non-milk sales. It has the following form

$$\begin{aligned}\text{Cost/cow} = {} & D_0 + D_1 \text{ production/cow} + D_2 \text{ farm size (cows)} \\ & + D_3 \text{ owner's age} + D_4 \text{ owner's education} \\ & + D_5 \text{ technology index} + D_6 \text{ pr(MIRG)} \\ & + D_7 \text{ Pct non-milk revenue.}\end{aligned} \tag{6}$$

Following the results reported in the literature[11,13], costs are expected to increase in production, age, the percent of non-milk revenues, and the technology index; and to decrease in education and farm size. The literature on grazing suggests that MIRG should lower costs.

The profit equation shown below in equation (7) will have the same form and variables as the cost equation

$$\begin{aligned}\text{Profit/cow} = {} & E_0 + E_1 \text{ production/cow} + E_2 \text{ farm size (cows)} \\ & + E_3 \text{ owner's age} + E_4 \text{ owner's education} \\ & + E_5 \text{ technology index} + E_6 \text{ pr(MIRG)} \\ & + E_7 \text{ Pct non-milk revenue.}\end{aligned} \tag{7}$$

Since the average size of Connecticut dairy farms has been increasing for the past decade, we hypothesize that there are increasing returns to scale, so we expect the farm size coefficient (B_2) in the profit equation to be positive. Profits are expected to be increasing with management ability and with use of more production-increasing technology. The literature provides little guidance on the hypothesized sign for the coefficients on both the percent non-milk revenue and on MIRG.

In addition, because potentially the degree of adoption of MIRG influences farm outcomes, the number of monthly rotations is included in the analysis. Preliminary estimations suggested that the degree of adoption did

not significantly influence productivity or cost, so only a profit model is presented. (Results of the productivity and cost estimations using monthly rotation and monthly rotation squared are available from the authors.) A profitability of rotation model is estimated with the following form

$$\begin{aligned}\text{Profit/cow} = {} & F_0 + F_1 \text{ production/cow} + F_2 \text{ farm size (cows)} \\ & + F_3 \text{ owner's age} + F_4 \text{ owner's education} \\ & + F_5 \text{ technology index} + F_6 \text{ monthly rotation} \\ & + F_7 (\text{monthly rotation})^2 \\ & + F_8 \text{ Pct non-milk revenue.} \end{aligned} \quad (8)$$

Following the results of Hanson et al.[8,9], we expect a quadratic relationship between profits and rotation intensity (the most profitable will be either no rotations or high rotations).

Results

The adoption equation shown in Table 3 gives a number of hypothesized effects. Farmers with more rented land were less likely to adopt MIRG, probably because of the implied distance from barn to the land. Also, farmers with higher education were significantly more likely to graze their animals, suggesting that education levels were quite important in the management part of rotational grazing.

The production equation, shown in Table 4, has an R^2 of 0.32. Since the coefficient on farm size is not significant, we find no indications of returns to scale in the dairy industry. The technology index has a positive parameter that is significantly different from zero, which may be masking some of the scale effects, since larger farms are more likely to adopt new technologies. Surprisingly, given the big, though statistically insignificant differences in average productivity, being an MIRG user has no significant influence on productivity. The results suggest very little penalty for being an MIRG user in terms of productivity, when one has controlled for other factors.

Table 5 shows the cost per cow estimates, which produces an R^2 of 0.32 and significant and positive coefficients on production and percent of non-milk revenues. The coefficient on engaging in MIRG is insignificant, though surprisingly positive. One must conclude, as found by Winsten et al.[10], that in the Northeast there is no significant lowering of cost per cow by using MIRG, when one controls for other factors.

Given the insignificant effects of MIRG on both costs and milk per cow productivity, one would expect the same result for profits. Table 6 shows the profit function estimates, which estimate with an R^2 of 0.18. They show that more profitable farms are those with more non-milk revenues and have younger owners. They also show that greater technology use, despite the increases in productivity it yields, produces significantly lower profits. The results on MIRG show no significant effects of being a grazer on overall farm profits.

In order to better specify the effects of grazing on profits, Table 7 reports the relationship between profits and the intensity of rotation as measured by the number of times per month the cows change pastures. Though they are not significant, the results look similar to those using the predict probability, pr(MIRG), with lower profits for MIRG users.

Table 3. Adoption probability probit model: log likelihood = −44.443077; observations = 121.

Pr(MIRG) Variable	Coefficient	Standard error
Owned land	−0.000843	0.0013721
Rented land**	−0.0030913	0.0015337
Age	−0.0116459	0.0152558
Education**	0.2033975	0.0842516
Number of hires	−0.0131597	0.0785434
Years farmed	0.0018728	0.0021344
Constant**	−2.819935	1.414532

Significance level: ** 5%.
Percent predicted correctly: 85%.

Table 4. Production equation: $R^2 = 0.32$; observations = 101.

Production/cow (1000 lbs) Variable	Coefficient	Standard error
Farm size (cows)	0.0058659	0.0055775
Age	0.0437567	0.0347566
Education	0.1427541	0.1603475
Technology index***	0.6237582	0.1576792
Pr(MIRG)	0.8214412	3.168248
Constant***	9.995329	2.854259

Significance level: *** 1%.

Table 5. Cost equation: $R^2 = 0.32$; observations = 81.

Cost/cow ($) Variable	Coefficient	Standard error
Production per cow***	90.20284	31.35843
Farm size (cows)	−0.6813033	1.554239
Age	2.032988	9.406923
Education	−10.98245	52.08137
Technology index	68.03312	49.76473
Pr(MIRG)	619.965	917.7132
%Non-milk revenue*	3110.095	1880.595
Constant	38.23531	522.9367

Significance levels: * 10%, *** 1%.

Table 6. Profit equation: $R^2 = 0.18$; observations = 81.

Profit/cow ($) Variable	Coefficient	Standard error
Production per cow	13.72707	15.02282
Farm size (cows)	0.1960464	0.415381
Age**	−7.790699	3.759303
Education	14.12211	21.97333
Technology index**	−66.32693	25.5455
Pr(MIRG)	71.87377	504.004
%Non-milk revenue**	585.4505	254.1119
Constant**	756.917	327.7958

Significance level: ** 5%.

Table 7. Profit equation: $R^2 = 0.20$; observations = 81.

Profit/cow ($) Variable	Coefficient	Standard error
Production per cow	11.92145	15.26732
Farm size (cows)	0.051359	0.04004051
Age	−6.611251	3.933221
Education	19.48925	18.1842
Technology index***	−71.23166	24.96188
Monthly rotation	−13.89002	8.499295
(Monthly rotation)^2**	0.3122173	0.1507565
%Non-milk revenue**	606.8594	269.5364
Constant**	735.262	379.4357

Significance levels: ** 5%, *** 1%.

There is a suggestion from the quadratic term in these results that farms engaging in grazing but rotating their pasture slowly, have lower profits than either those who do not use rotational grazing at all or those who rotate their cows faster between pastures. These results differ from those of Hanson et al.[8,9], in that while management intensive rotational grazing is not found to significantly influence milk production, the quadratic form of the influence of increased grazing rotation on total farm profits is significant. This result has important policy implications for extension agents working with potential grazers. The results suggest that profitability from grazing can be found for those who have a rapid rotation of their cows, but that farmers who dabble in grazing may not be improving their bottom line.

Conclusion

This work has estimated econometric models to show the adoption probabilities and effects on costs, productivity, and profits of Connecticut dairy farms using management intensive rotational grazing. MIRG adopters are shown to have more education and less rented agricultural land (a proxy for lack of access to land within a short distance of the barn). MIRG adoption had no significant effects on costs, productivity, or profits. Evidence was found, however, to suggest that full adopters of the technology had more profitable farms than partial adopters. This finding supports the conclusion of Hanson et al.[8,9] that farms that employ more intensive rotational grazing practices can have higher returns than farms that use extensive grazing. Equally importantly, non-grazing technology adoption raised costs and production while lowering profits significantly for all types of farms.

Given the difficulty in finding land that is easily accessible to barns in Connecticut, there would seem to be little room for expansion of rotational grazing. The significant negative relationship between rented land as a component of total farmland, a proxy for ease of cow movement, on MIRG adoption suggests such a limit to grazing expansion.

The results do suggest that MIRG technology may be a viable option for some Connecticut dairy farmers, and that it is most profitable with full adoption. This suggests that extension efforts on grazing might be best directed toward increasing the profitability of those who are currently grazing their animals. With the small average size of grazing farms in Connecticut, an extension effort on increasing MIRG profitability may be one of the better methods to reach the smallest dairy farms and help keep them in business.

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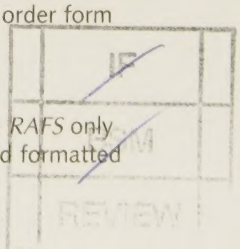

Renewable Agriculture and Food Systems

Volume 20 Number 4 December 2005

Review Article

Comparison of consumer perceptions and preference toward organic versus conventionally produced foods: A review and update of the literature
Emmanuel K. Yiridoe, Samuel Bonti-Ankomah and Ralph C. Martin 193

Research Papers

Organic cucumber production in the greenhouse: A case study from Turkey
Y. Tuzel, A. Gul, O. Tuncay, D. Anac, N. Madanlar, Z. Yoldas, M. Gumus, I.H. Tuzel and S. Engindeniz 206

Substrates and fertilization for the rustic cultivation of *in vitro* propagated native orchids in Soconusco, Chiapas
Anne Damon, Marco Pérez Soriano and Maria del Lourdes Rivera 214

An integrated approach to crop/livestock systems: Forage and grain production for swath grazing
D.L. Tanaka, J.F. Karn, M.A. Liebig, S.L. Kronberg and J.D. Hanson 223

An integrated approach to crop/livestock systems: Wintering beef cows on swathed crops
J.F. Karn, D.L. Tanaka, M.A. Liebig, R.E. Ries, S.L. Kronberg and J.D. Hanson 232

Farmer research: Conventional experiences and guidelines for alternative agriculture and multi-functional agro-ecosystems
C.S. Wortmann, A.P. Christiansen, K.L. Glewen, T.A. Hejny, J. Mulliken, J.M. Peterson, D.L. Varner, S. Wortmann and G.L. Zoubek 243

Marketing locally produced foods: Consumer and farmer opinions in Washington County, Nebraska
Mindi L. Schneider and Charles A. Francis 252

The adoption and impact of management intensive rotational grazing (MIRG) on Connecticut dairy farms
Jeremy Foltz and Gillis Lang 261

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